DIGITAL HYDRAULIC VALVING SYSTEM
FINAL REPORT

Submitted by: HLM, Inc.
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Contract NAS 8-28166 August 24, 1973

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HLM, INC.

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INDEX

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DIGITAL HYDRAULIC VALVING SYSTEM

FINAL REPORT

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1. INTRODUCTION

In compliance with contract NAS 8-28166, this report is presented. It documents the design and development of a Digital Hydraulic Valving System.

On September 11, 1972 a "Trade-Off Study" report was submitted to NASA/MSFC, attention of Mr. Paul Golley, for evaluation. This study presented various approaches to development of a Digital Hydraulic Valving System. The design approach chosen by NASA/MSFC for detailed study, fabrication and evaluation was the "Pulse Motor with Hydraulic Helix Coupling to Pilot Valve Controlled Power Spool".

The "Trade-Off Study" report also presented various schemes for interfacing the Digital Valve with the digital electrical command signal. The electrical control approach and command signal format was selected by the contractor (HLM, Inc.), with the approval of NASA/MSFC. This approach was analyzed and defined in detail in a special status report to Mr. Paul Golley of NASA/MSFC, titled "Status Report on the Electrical Control for the Digital Hydraulic Valve System", dated December 4, 1972.

2. SUMMARY OF CONTRACTUAL ACCOMPLISHMENTS

As called for in the "Scope of Work" of the contract, HLM, Inc. did initiate and conclude a trade off study of various servovalve devices that would accept direct digital inputs. The results of this trade-off study were used to design and fabricate a prototype digital valving system, which was subsequently tested. The valving system achieved the predominant design objectives of:

a) Interfacing with an 8-bit Digital Word Command.

b) Controlling a primary actuator with hydraulic power levels of 10 gallons/minute at 3000 psi.

Other specifications that the Valve achieved or exceeded were:

a) Power spool stall force capability of nominal 600 pounds (actual 508 pounds to utilize standard seals).

b) Power spool maximum flow rate of 10 gallons/minute.

c) Working system pressure of 3000 psi.

d) Commanded position resolution of 1% of the power spool maximum travel.

e) Hysteresis of less than 1% at 3000 psi system pressure.

The electrical system controls were to operate from an electrical supply of 28 V.D.C. In the interest of securing off-the-shelf components for the electrical system, the prototype hardware supplied requires 48 V.D.C. and 5 V.D.C. This deviation would not be required for future hardware, if the vendor is given sufficient "lead time" to design the necessary circuits for 28 V.D.C. operation. For the prototype unit, HLM, Inc. supplied a 115 V.A.C. input power supply to generate the 48 V.D.C. and 5 V.D.C. voltages required. Finally, the valve system was limited in frequency response by the characteristics of the electrical stepper motor. This aspect of the project is discussed in great detail in this report under section 5 "Conclusions". The system as supplied, without use of any unique stepper motor circuit techniques (in the interest of limiting electronic complexity) is capable of a system response (including the Government furnished actuator) that is flat to 10 HZ. This is theoretically extendable to 12 HZ, but was not demonstrated because of the limitations of the "Digital Bus Signal" simulator that was added to the system for test purposes only (not a part of this study contract).

3. DESIGN AND FUNCTION DESCRIPTION

3.1 SERVOVALVE DESIGN CONCEPT

The servovalve design concept consists of a stepper motor with hydraulic helix coupling to a pilot valve controlled power spool. This arrangement is shown in figure 3.1a and HLM, Inc. drawing #2895.

In essence the device consists of a stepper motor, a pilot spool with a coaxial power spool, and a valve body. The stepper motor is directly coupled to the pilot spool through a bellows type zero backlash coupling. The pilot spool is axially restrained between a pair of thrust ball bearings, both lubricated by the surrounding hydraulic fluid at return pressure. Thus the pilot spool accepts only rotary inputs from the stepper motor. A helical land on the pilot spool nulls between a pressure port and a return port in the coaxial power spool. A control pressure (C) is created in the helical groove and ported to an annular area (Ac) on one end of the power spool. System pressure is ported to an annular area (Ap) on the opposite end of the power spool. The control pressure is determined by the following expression.

$$C = \frac{PAp}{Ac}$$

$$= \frac{3000\ (.173)}{.352} \quad = \quad 1465 \text{ psi}$$

System pressure acting on one end of the power spool is balanced by control pressure on the opposite end. The power spool must be free to translate axially but must be restrained from rotation. This is accomplished by providing an adjustable conical pin in the valve body which engages in a tapered slot in the power spool outside diameter. Adjusting the pin position by means of a screw thread provides the necessary clearance without contributing significant backlash. To demonstrate this:

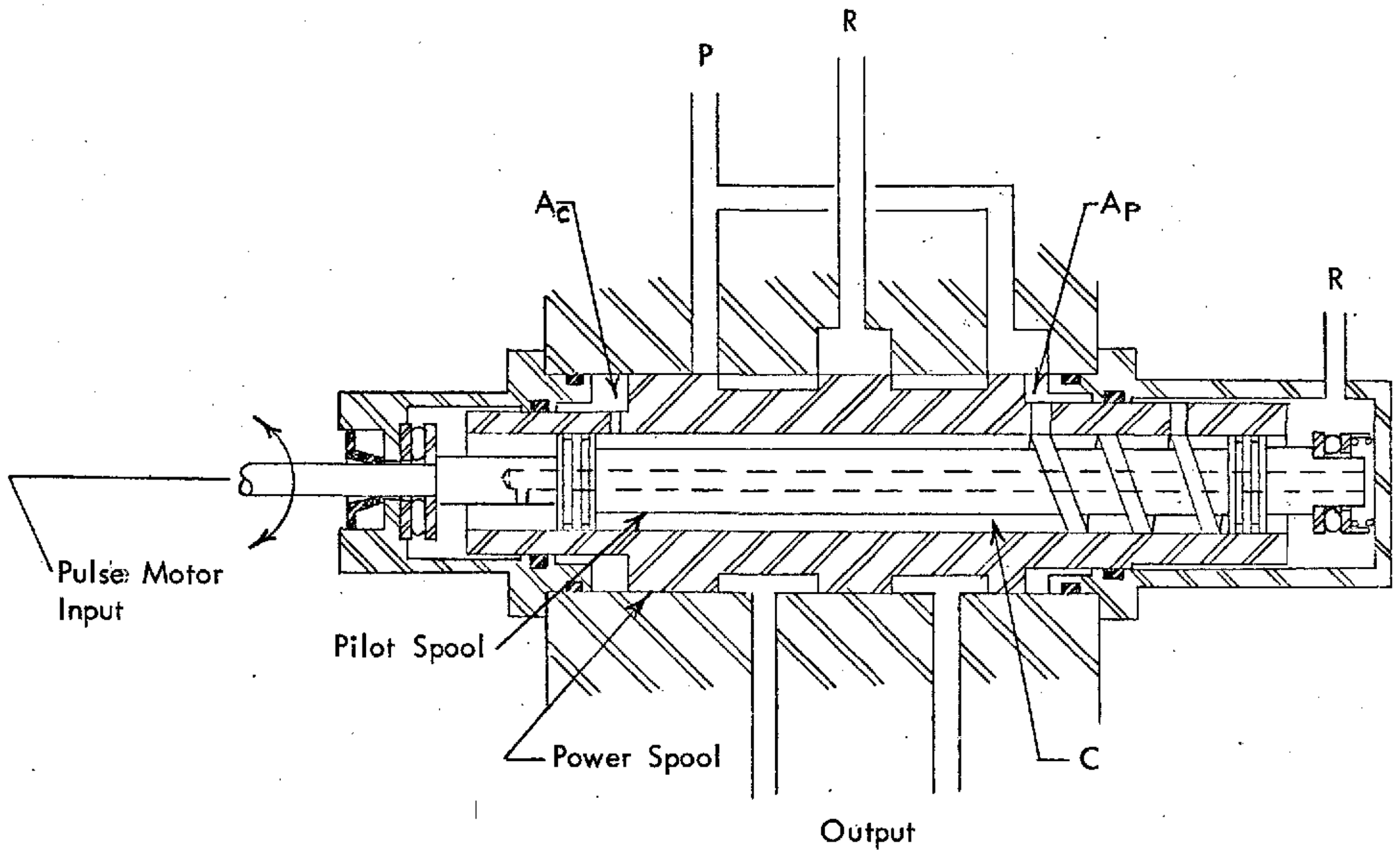
Input spool rotary motion = ± 45°

Power spool slot O.D. = 0.687 in.

Pin/slot clearance = .0005 in.

$$\text{Angular backlash} = \frac{.0005\ (360)}{(0.687)\ \pi} \quad = \quad .083 \text{ degrees}$$

$$\text{Backlash} = \frac{.083}{45} = 0.18\%$$



Pulse Motor with Hydraulic Helix Coupling
to Pilot Valve Controlled Power Spool

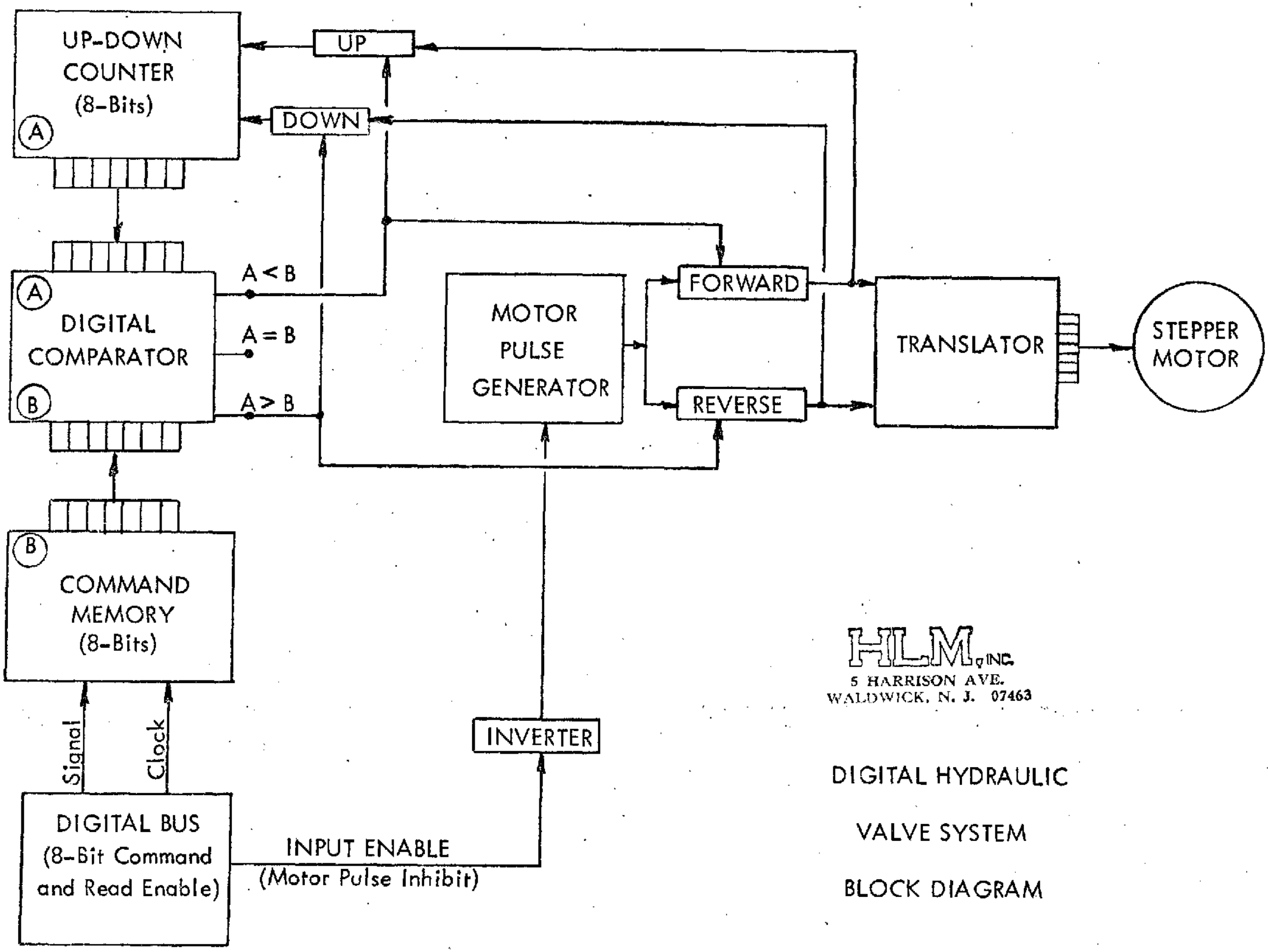
Figure 3.1a

The power spool has four null surfaces as in a conventional servovalve. The hydraulic follower (pilot helix) has two null surfaces. Depending on the required dynamic response, the valve can be designed to have no steady state pilot flow (other than leakage) or a small amount, but always significantly less than a conventional servovalve. This is the case because a conventional servovalve must have a steady state first stage flow equal to twice the maximum instantaneous flow required to drive the power spool, while this experimental valve always requires less steady state flow than the maximum instantaneous flow to drive the power spool. With an axis cut null condition of the input spool the steady state pilot flow approaches zero. This is discussed in section 4.2 of this report in more detail. Indexing the valve center position to the zero signal stepper motor position is accomplished at the shaft coupling or at the motor mounting screws.

The only load to burden the stepper motor is friction due to rotating the pilot spool in the power spool bore, at the thrust ball bearings, and at the low return pressure shaft seal; all very low. The only external inertial load on the stepper motor is the pilot spool and its coupling to the motor; also very low. The stepper motor has a torque capability of 28 inch pounds at 1500 pulses per second. The coaxial design permits a compact package made up of a few precise parts. No orifices, nozzles, or flappers are required. The mechanical design due to its few parts, lack of orifices, and few seals as well as its low motor burden should provide a high mechanical reliability. The mechanical parts are few, though precise, and if properly tooled should provide a relatively economical design comparable to conventional servovalves.

3.2 CONTROL CIRCUIT

The basic electrical circuit for the control of the stepper motor that drives the Hydraulic Helix Coupling Valve package is shown on HLM, Inc. drawing #2486 Rev. A. This circuit was modified to provide for the addition of a "Digital Bus Signal" simulator for test purposes. This modified circuit is shown in detail on HLM, Inc. drawing #2918; the latter represents the circuit configuration of the hardware actually delivered to NASA/MSFC. This circuit will be discussed in greater detail after a general description of the system has been presented with the help of the block diagram shown in figure 3.2a. This block diagram illustrates only those details that would aid in understanding the basic concept of the system. The 8-bit word command (signal and clock) is generated by the Digital Bus terminal and is the input command to the valve system under study. This terminal also generates an "Input Enable" signal, which inhibits motor pulses from being generated while a command is being read into the system. In this manner serial information (or parallel information with minor modifications) may be transferred into the 8-bit Command Memory section of the control circuit. Here the command is stored in parallel form and connected to one input side of an 8-bit Digital Comparator. The other input side of the Digital Comparator is connected to the output of an 8-bit Up-Down Counter. This Up-Down Counter is used to indicate the position of the stepper motor, since, every "forward" step pulse that is routed to the motor is also sent to this Counter



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DIGITAL HYDRAULIC
VALVE SYSTEM
BLOCK DIAGRAM

Fig. 3.2a

as an Up count of 1 pulse, and every "reverse" step pulse that is sent to the motor is also sent to the Counter as a Down count of 1 pulse. Hence, the Up-Down Counter provides a memory of the motor shaft position at a given time.

From the foregoing it should be obvious that the Digital Comparator is comparing the actual position of the motor shaft (Up-Down Counter output "A") with the commanded position desired (Command Memory "B"). If both are equivalent, an output will appear at the Comparator terminal A = B, resulting in no action of the motor or Counter.

If the commanded position (B) is higher than the motor shaft position (A), then an output will appear at the Comparator terminal A<B. This will result in the routing of pulses from the Motor Pulse Generator to the Stepper Motor through the "forward" channel of the Translator. Also, at the same time these pulses are synchronously routed to the Up-Down Counter, which has its "Up" count terminal activated by the Comparator's A<B signal. These pulses will continue synchronously to both the Motor and the Counter until the Counter tally (A) has been increased in value to equal the Command signal (B), at which time the Comparator will nó longer indicate a signal at A<B, but instead will indicate a signal at A = B. The turning "off" of the signal at A<B will interrupt the flow of pulses from the Motor Pulse Generator to both the Motor and the Counter. In this way the commanded signal will have been executed.

If the commanded position (B) is lower than the Stepper Motor shaft position (A), then an output signal will appear at the Comparator terminal A>B. Note that negative commands are treated as being smaller than positive commands, as in the standard system of numbers. This will result in the routing of pulses from the Motor Pulse Generator to the Stepper Motor through the "reverse" channel of the Translator. Also, at the same time these pulses are synchronously routed to the Up-Down Counter, which has its "Down" count terminal activated by the A>B signal. These pulses will continue synchronously until the Counter tally (A) has been decreased in value to equal the Command signal (B), at which time the Comparator will turn "off" its A>B signal and turn "on" its A = B signal. This results in the stopping of the flow of pulses to the Motor and Counter, since the commanded signal has been executed.

The foregoing demonstrates how a digital command can be used to control the position of a Stepper Motor shaft. The actual hardware is shown on HLM, Inc. drawing #2896 (Electrical Control Assembly) and HLM, Inc. drawing #2918 (Control Circuit). The instructions for operating this equipment are attached to this report in Appendix A. (Electrical Control Circuit - Operating Procedure).

The input command signal is an "Absolute Digital Word" command, proportional to the flow rate and direction desired (forward or reverse). The 8-digit word command provides for at least 100 discrete flow rates (1% resolution) in each direction. This signal must be compared with an Up-Down Counter that generates negative numbers in the "Two's Complement" form (see the chart titled "Binary Coded Equivalent of Digital Values", in Appendix A). Hence, the input command must be in this form for valid comparisons by the Digital Comparator.

The schematic (HLM, Inc. drawing #2918) illustrates the means of inputing the command signal manually. This is called the "Manual Signal Simulator" and is in reality the "Digital Bus Signal" simulator mentioned in previous sections; its operation is detailed in the Operating Procedure contained in Appendix A of this report. It effectively replaces the Digital Bus signals and the 8-stage Shift Register (780-2834) shown on drawing #2918. The signal that is generated by the Manual Signal Simulator" is routed to the Comparator through Connector J-4B and Plug P-4. The circuit elements are made up of integrated circuit cards of the Diode-Transistor-Logic type supplied by Cambridge Thermionic Corp. The Comparator consists of two 4-bit parallel Binary Comparators (780-3409) in cascade. The Up-Down Counter, which also is connected to the Comparator, consists of two 4-stage Counters (780-2609) in cascade. The Motor Pulse Generator consists of the Free Running Multivibrator (780-5909) and its integral NAND gates which are used for synchronously gating the pulses out to the Motor and Counter in such a manner that the full width of the starting and ending pulses is preserved. This standard circuit card (780-5909) has been modified slightly as defined by HLM, Inc. drawing #2893. Also the pulse rate is adjustable by changing the capacitors at terminals E1-E2 and E3-E4. A chart is shown on the HLM, Inc. drawing relating nominal capacitor values to pulse rate. The card supplied has capacitors to generate a frequency of 1550 HZ.

The Control Circuit (2893) also shows distributed throughout the circuit inverting Buffer/ Drives. These are located on printed circuit card 780-5584. This standard circuit card is also modified slightly as defined by HLM, Inc. drawing #2894. These logic elements are used as signal inverters and as amplifiers for pulse shaping and load driving. The modifications shown on drawing 2894 are simply a means of expanding 3 of the Inverters into 3 - NAND gates. These modifications are only an economy measure since we limited our hardware to standard off-the-shelf hardware.

The pulses that step the motor are routed to it through a Mesur-Matic Electronics Corp. type DD-6 Motor Driver. This is a circuit that performs the function of "translating" each input pulse into a sequenced output to the eight Stepper Motor phases to advance its shaft the commanded number of steps in the proper direction. The mode of operation of this circuit is such that 3 adjacent phase coils (of the 8) are energized at all times. Thus, when the system is initially started, phases 1, 2, and 3 may be energized by pressing the "Motor Phase Reset" switch. This places the motor shaft in one of its eight unique adjacent positions. However, these eight positions are repeated 100 times for a complete revolution (360°) of the motor shaft. Hence, there is an ambiguity possible with regard to which of these 100 groups the shaft is positioned within. For this reason whenever the system is started, the valve must be positioned approximately at null (within ± 1 1/2 degrees) before the motor power is turned "on" and the "Motor Phase Reset" switch is actuated. This need for aligning the Stepper Motor is a common problem with "open loop" control systems in which the position of the motor shaft is remembered by an Up-Down Counter. Other methods of indicating the motor shaft position, such as, shaft mounted feedback elements, have their own associated problems. Solutions to the shaft alignment problem are possible, but only after a consideration of the entire system within which the valve is a component.

The Stepper Motor is driven by the "DD-6" Driver Unit through the Mesur-Matic type DY11 Chopper Driver Constant Current Power Supply. This circuit applies full high voltage (20 times motor voltage) for rapid increase of motor winding current to its maximum continuous duty value, at which time the voltage is switched on and off to maintain this high current in the winding during the stepping interval for maximum stepping torque (and acceleration).

This brings us to the connection of the driving circuit to the eight phase coils of the Stepper Motor itself. The motor was selected on the basis of a unit that could step at a rate of approximately 2000 steps per second, with the use of a minimum of electronic circuitry. Also it must have high acceleration and deceleration, and dynamic resonances above the operating speed range. The step angle should be small (less than 1 1/2 degrees) to aid in the design of the control valve helix; this feature is desirable, but not absolutely necessary. The nutating drive design stepper motor selected (Mesur-Matic Electronics Corporation) has an error-free start and stop specification of 1600 steps per second with inertial loads comparable to our valve, without need for special electronic circuits. It has high torque output (28 in-lbs) and low inertia due to its integral 100 to 1 gear reduction. Its step angle is 0.45 degrees, so that the complete output shaft rotation is only 90 degrees for ± 100 discrete flow selections. The shaft of this Stepper Motor is coupled to the servovalve as described in section 3.1.

4. VALVE PARAMETERS AND CALCULATIONS

4.1 DESIGN PARAMETERS

1. Power Spool net area = 0.169 sq. in.

2. Power Spool stall force @ 3000 psi = 3000 (.169)
   = 508 lbs.

3. Power Spool Travel = ± .025 in.

4. Valve Output flow @ 1000 psi valve drop = 10 gpm = 38.5 c.i.s.

5. $$A = \frac{Q}{101\sqrt{\Delta P}}$$

   where A = metering area - sq. in.
   Q = Flow - c.i.s.
   ΔP = Press drop across A - psi

   $$= \frac{38.5}{101\sqrt{500}}$$

   = .0171 sq. in.

   $$\text{Width of slot} = \frac{A}{(\text{travel})\ (\text{Number Slots})} = \frac{.017}{.025\ (4)}$$

   = .170 in.

6. Bernoulli Force at Power Spool = 0.43 AΔP

   = 0.43 (.017) (1000)

   = 7.3 lbs.

   Power Spool net area = 0.169 sq. in.

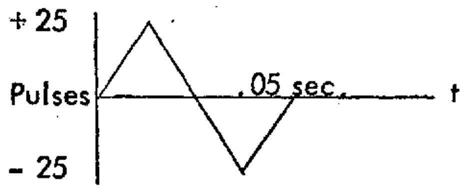
   $$\Delta P \text{ across spool due to Bernoulli} = \frac{7.3}{.169}$$

   = 43 psi at max flow

7. 1 Pulse of motor displaces power spool 1% of max travel.

   1 Pulse of motor displaces power spool .00025 in.

8. Response to be flat to 20 HZ (at 1/4 max amplitude) at 20 HZ, cycle time = $\frac{1}{20}$ = .05 sec.



100 Pulses/cycle @ 25% Rated Input

$$\text{Motor avg. Pulse rate @ 20 HZ} = \frac{100}{05}$$

$$= \underline{2000 \text{ Pulses/sec.}}$$

9. Motor rotation per pulse = 0.45 degrees
Max. signal = ± 100 pulses
Max. shaft rotation ± 100 (0.45) = ± <u>45 degrees</u>

10. 45° shaft rotation must displace power spool .025 in.

$$\therefore \text{ Helix pitch} = \frac{.025\ (360)}{45} = \underline{0.200 \text{ in.}}$$

11. Helix Dia d = 0.312 in

where α = Helix Angle
h = Pitch

$$\tan \alpha = \frac{h}{\pi d}$$

$$= \frac{.200}{\pi\ (.312)} = 0.204$$

$$\underline{\alpha = 11.52 \text{ degrees}}$$

4.2 NULL CONDITIONS - INPUT SPOOL

Response flat @ 20 HZ, 1/4 signal

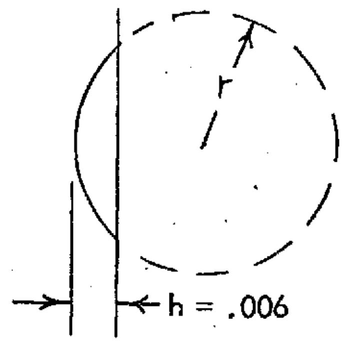
Flow to move power spool @ 20 HZ $= \dfrac{(.0125)\ \pi\ (20)\ (.34)}{4}$

$= 0.67$ cis

Metering Area $A = \dfrac{Q}{K\sqrt{\Delta P}}$

$$= \frac{.67}{101.5\sqrt{1500}} = 1.8 \times 10^{-4} \text{ sq. in.}$$

Metering Port Config.
$r = .039$



Assume $h = .006$ in.

$$\frac{h}{r} = \frac{.006}{.039} = .154$$

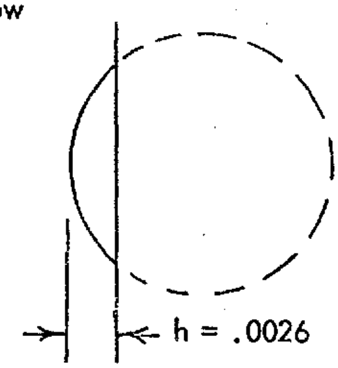
$$\frac{A}{r^2} = .111 \text{ from math tables}$$

$A = .111\ (.039)^2 = 1.7 \times 10^{-4}$ sq. in.

$\therefore$ port must be uncovered .006 in to provide flow

Total underlap provided = .0052

Which means at null
port is open .0026 in.



$\therefore$Spool must move
(.006-.0026) = .0034 in.
off null to meet response requirements @ 20 HZ

At null $\frac{h}{r} = \frac{.0026}{.039} = .0667$

$\frac{A}{r^2} = .032$ from math tables

$A = 032\ (.039)^2 = .487 \times 10^{-4}$ sq. in.

$Q = 101.5\ A\sqrt{\Delta P} = 101.5\ (.487 \times 10^{-4})\ \sqrt{1500}$

$= 0.18$ cis

$\therefore$ Quiescent Flow at Null = 0.18 cis excluding leakage.

This can be reduced to approach zero depending on dynamic requirements.

4.3 NULL CONDITIONS - POWER SPOOL

An axis null cut was attempted. This was achieved on three of the four metering lands of the power spool. On the fourth land an .001 inch null underlap condition exists. This condition creates a higher than normal centering pressure and more power stage leakage flow than would occur had an axis cut been achieved on this land. For the purposes of this program it did not seem worthwhile to fit a new power spool to eliminate this condition since second stage leakage flow was not judged critical in evaluation of the prototype valve.

5. CONCLUSIONS

5.1 VALVE HYSTERESIS AND PRESSURE GAIN

Valve hysteresis and pressure gain were determined by blocking the control ports and measuring pressure swing across the control ports as individual pulses were applied to the motor. In this fashion a hysteresis loop was generated. This data is plotted in figures 5.1a and 5.1b. Figure 5.1a shows data with 3000 psi applied to valve and figure 5.1b with 2000 psi applied.

At 3000 psi system, pressure gain is about 1300 psi/pulse or putting it another way 1300 psi per 1% of rated input signal. Hysteresis is 0.8%. The following table compares the data at 3000 psi and 2000 psi system pressures.

	3000 psi system	2000 psi system
Hysteresis % of rated input	0.8%	1.2%
Pressure Gain psi per 1% of rated input	1300	960

Several conslusions can be drawn from this data. Hysteresis compares very favorably with that of a conventional servovalve which is usually 3%. The hysteresis that is present is mostly friction. This can be seen by the fact that hysteresis increases as pressure decreases (constant friction would represent a greater percentage of driving force as system pressure is decreased). While hysteresis is excellent it can be decreased further by modifying the null cut of the input spool. The input spool is considerably underlapped (see discussion under section 4.2 Null Conditions). This was done to enhance dynamic performance. By reducing this underlap, the pressure gain of input spool would increase thus reducing the hysteresis even further. This would be worth demonstrating in a future valve.

The pressure gain data of the valve indicates that an input signal of 2% of rated signal, working into a blocked load, will provide a pressure swing equal to full system pressure across the control ports.

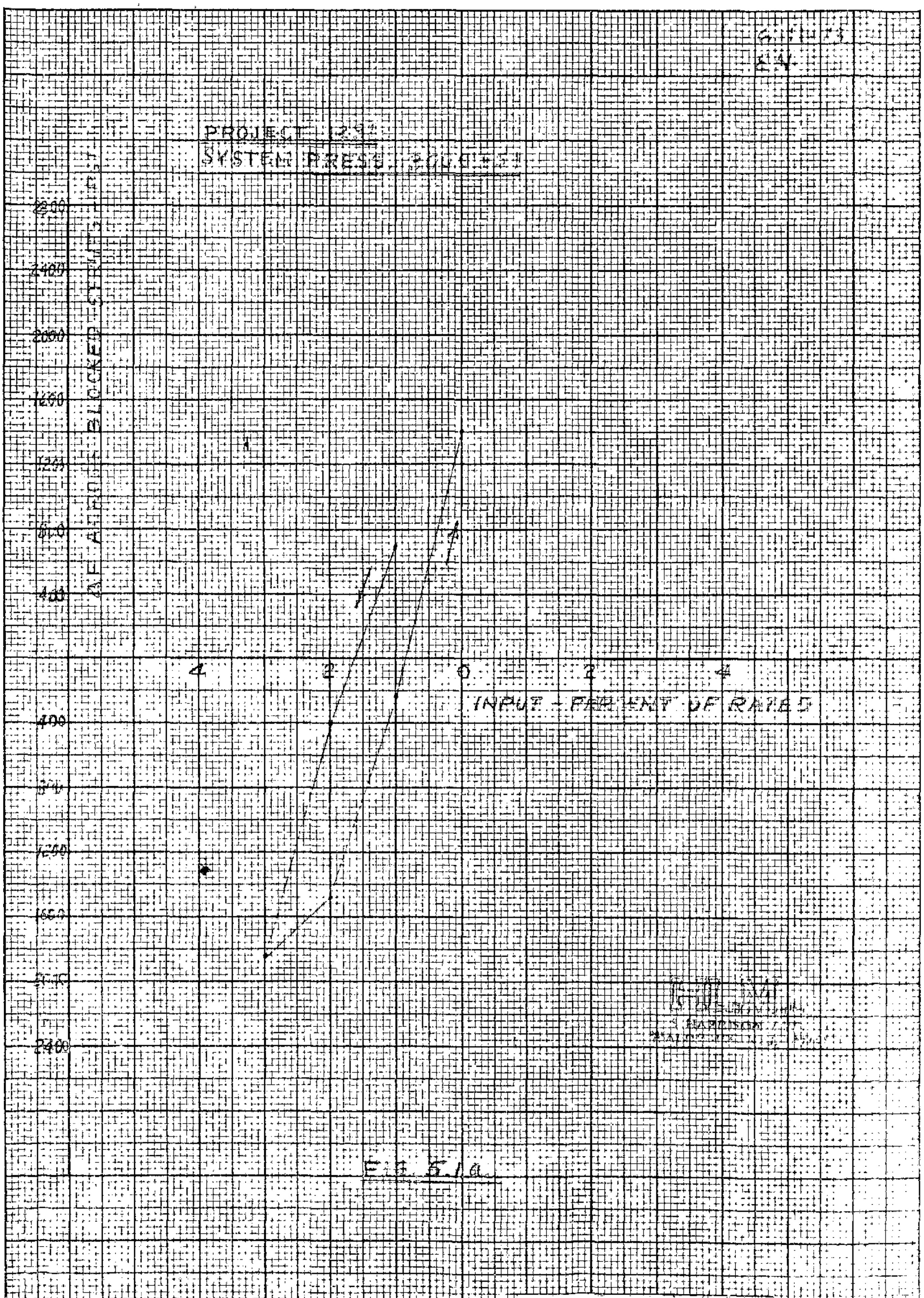


FIG. 5.1a

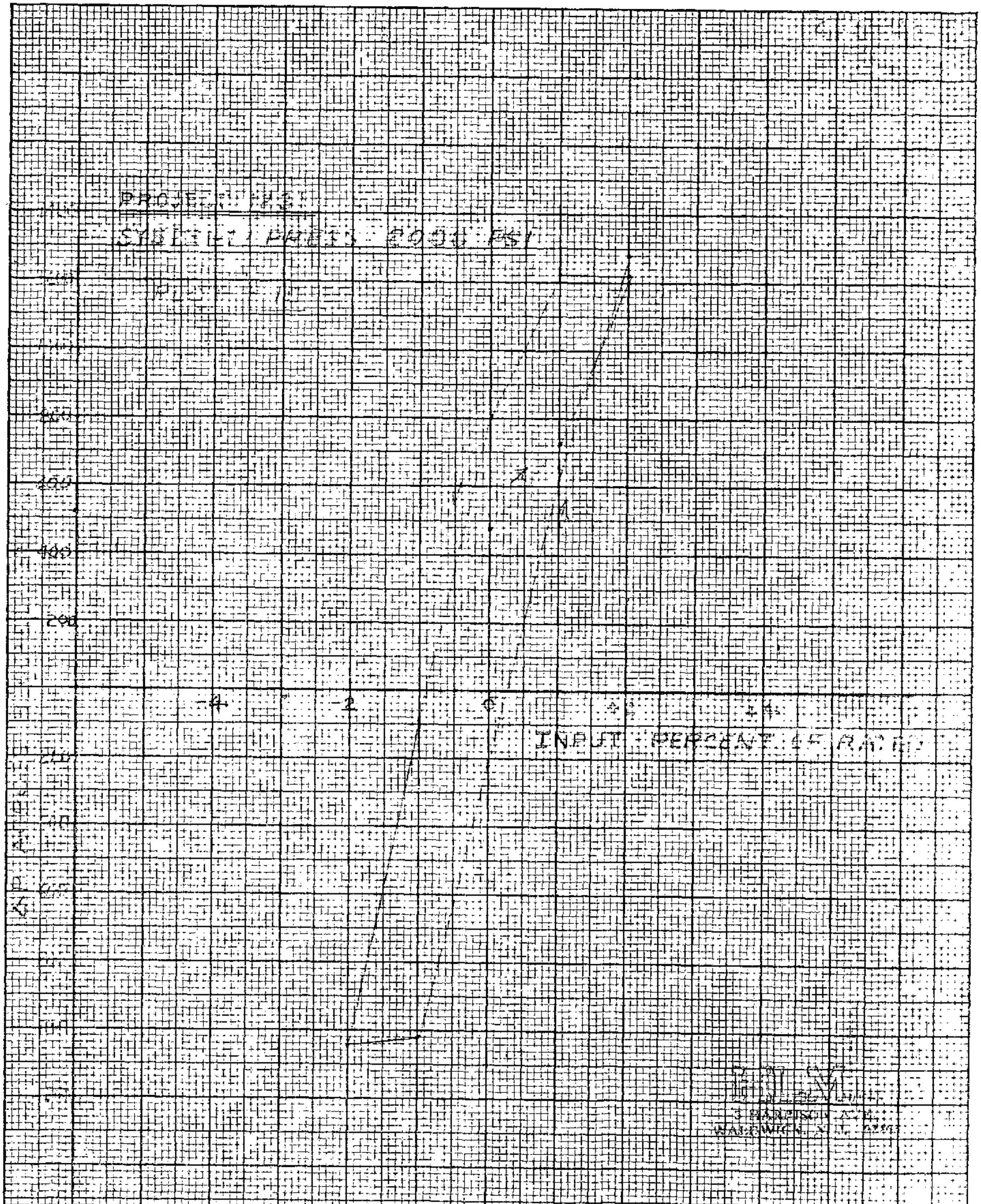


FIG. 5.16

5.2 SPOOL DRIVING FORCE

A conventional servovalve of equivalent flow capacity has a power spool driving force capability of 110 pounds at 3000 psi system pressure. The servovalve built for this program has a power spool driving force capability of 508 pounds at 3000 psi system pressure. Thus its "chip cutting" ability is significantly superior to that of a conventional servovalve. This in conjunction with the fact that it contains no orifices or nozzles enhances its operational reliability in the presence of hydraulic contamination.

5.3 FLOW GAIN AND LINEARITY

Flow data is plotted on figure 5.3a. This test was run with 3000 psi supply pressure and 1000 psi drop across the valve. Oil temperature ranged between 150 - 170°F. Due to flow limitation of the test stand hydraulic pump, data was obtained to 6 GPM rather than 10 GPM.

Flow gain was higher than planned, 0.169 GPM/% rated signal rather than 0.10 GPM/% rated signal.

Non-linearity was less than 5 percent. Conventional servovalves usually have a linearity envelope of ± 10 percent.

Null leakage was measured at 3000 psi to be 0.81 GPM. As discussed under section 4.3 on Null Conditions, a large percentage of this was due to an .001" underlap on one land of the power spool. First stage quiescent flow, exclusive of spool leakage, is estimated to be less than .05 GPM.

5.4 DYNAMIC RESPONSE

What is the most appropriate method to evaluate the dynamic response of a digital input servovalve? The question is deceptively simple. When one attempts to determine response in a manner that will measure its usefulness in a real system it becomes evident that the most useful means for a digital valve are not necessarily the same as those for an analog valve. Certainly measuring transient response to a step input applies equally well to both systems. This is not necessarily the case with frequency response. For analog systems a common means is to determine the relationship of no-load control flow to input current when the current is made to vary sinusoidally at constant amplitude over a range of frequencies. Frequency response is expressed by limits for the amplitude ratio and phase angle. When thinking about the digital valve a sinusoidal pulse input may not be a good simulation. Ideally, it is desirable to feed the pulses to the motor as fast as

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

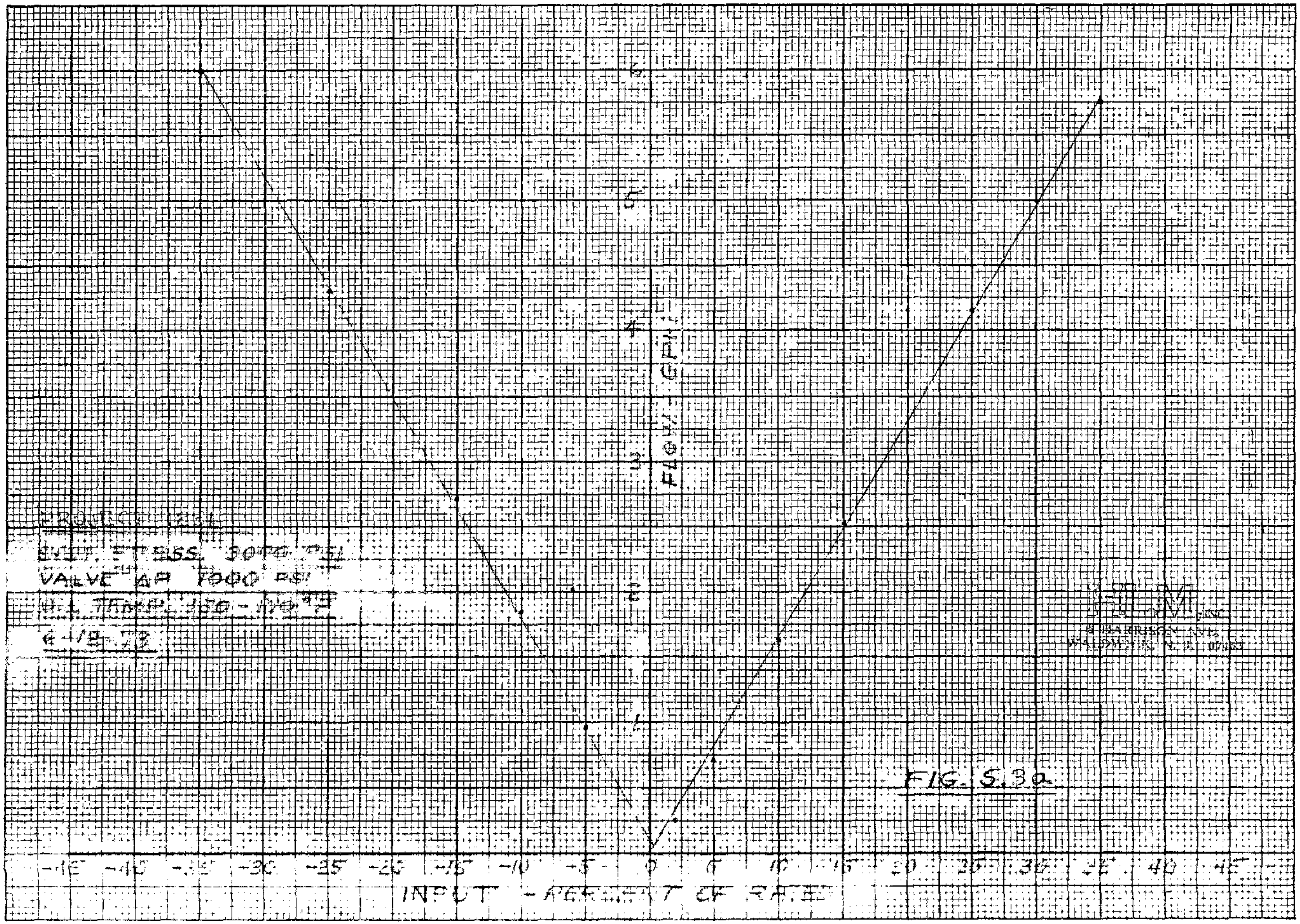


FIG. 5.3a

it will accept them. This could take the form of ramping in which there is controlled acceleration and deceleration. In order to keep the electronics relatively simple for this program no ramping was employed. The motor was fed input pulses at a constant rate.

The dynamic response of a package consisting of the digital input servovalve close coupled to a Moog Model 17-121F servoactuator was examined. The stepper motor alone was also tested.

The most significant conclusion that can be drawn is the limitation of dynamic response occurs at the stepper motor. Whatever is done to increase the response of the motor will increase the response of the system by approximately the same magnitude.

Transient response traces are shown on figure 5.4a through figure 5.4e for the valve/actuator package. This data is tabulated in the following table. Also included is the calculated time for the motor to transport the commanded increment.

Motor Input Pulses	Act. Response Time to Commanded Vel.	Motor Only Response Time	Remarks
0 to +8	.013 sec.	.005 sec.	Test method has a tol. of ± 5 msec due to wave form on recording line trace.
0 to +16	.014	.010	
0 to +32	.020	.020	
0 to - 32	.020	.020	
0 to +48	.030	.030	

From this it can be seen that the hydraulic valve does not detectably lag the motor. The lag time measured approaches the motor actuation time. This can be seen better on the frequency response data shown on figure 5.4f and 5.4h.

These traces were run on the valve/actuator package, open loop at approximately 2 HZ and 10 HZ. From these traces motor lag, motor transport, and total valve actuator response times can be determined. They are summarized below.

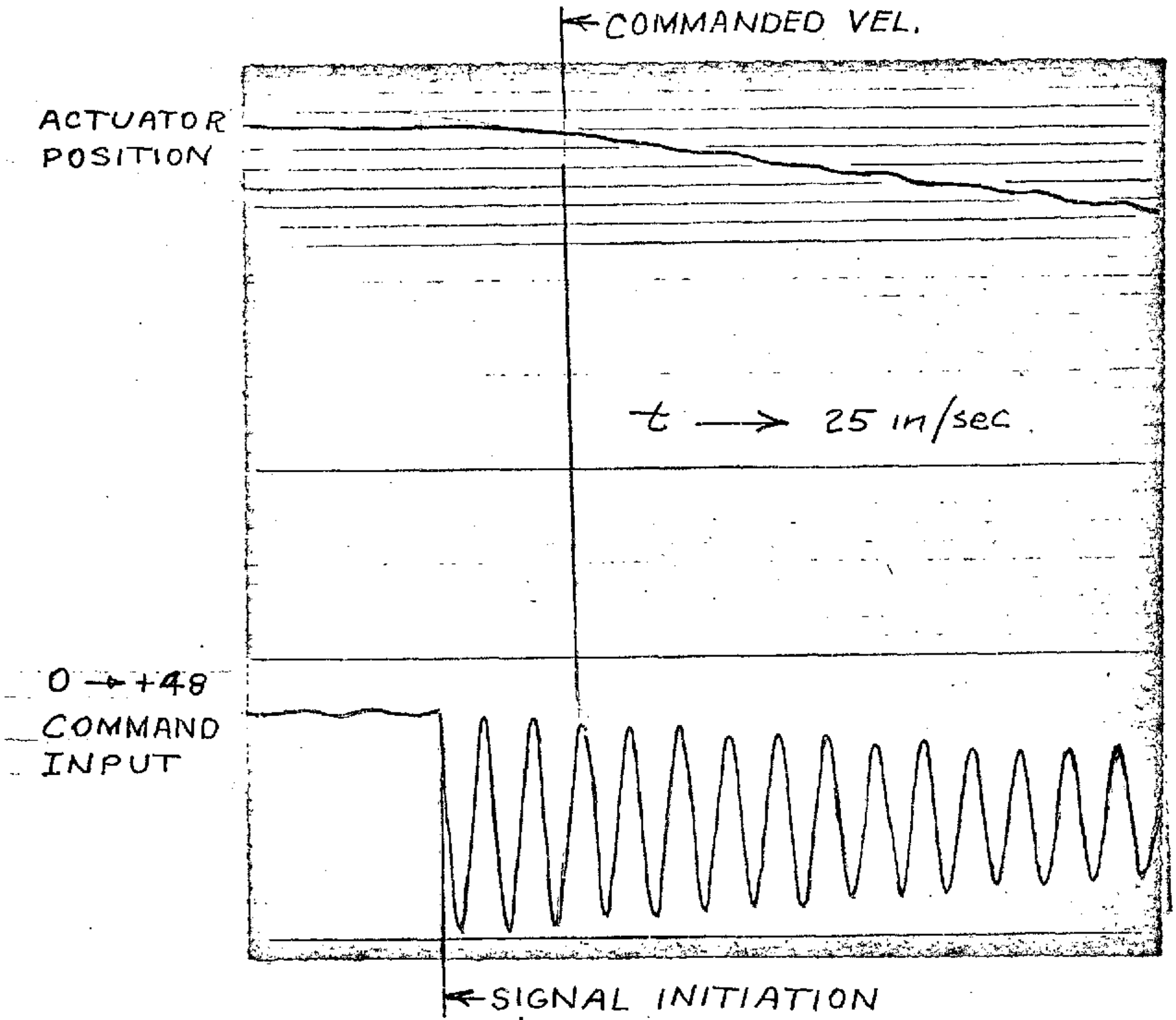


FIG. 5.4A

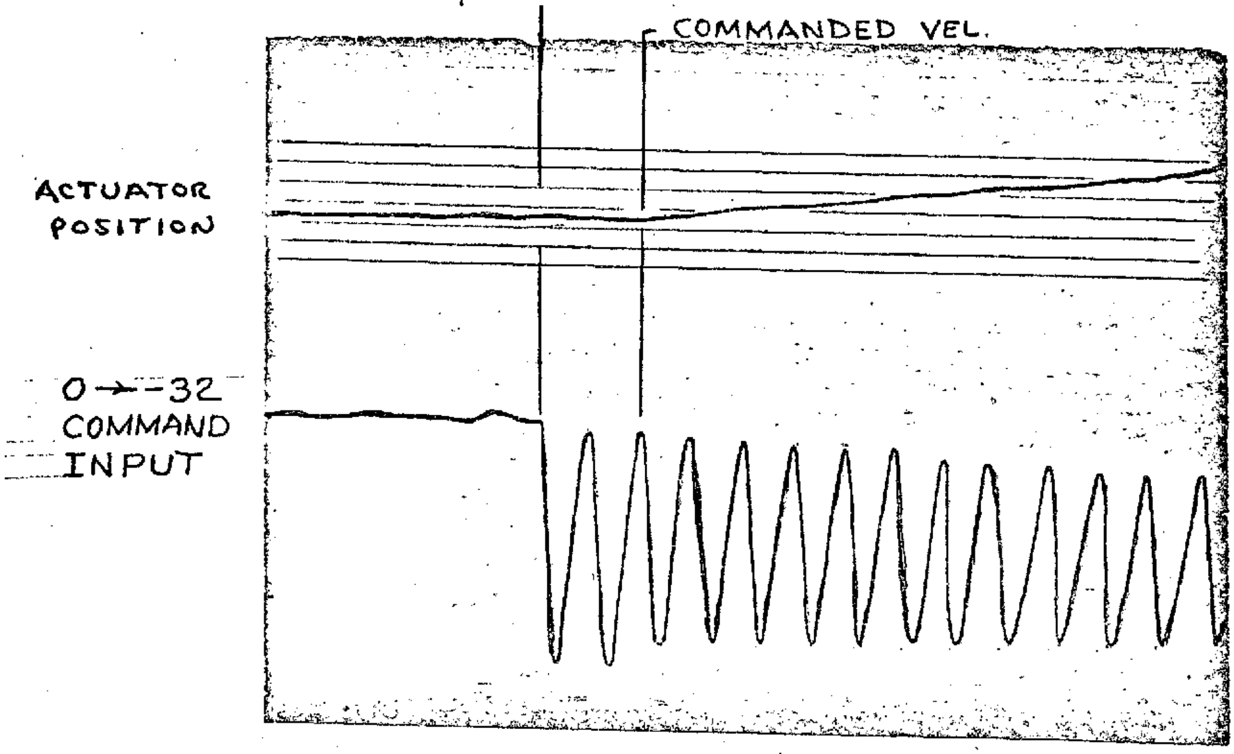


FIG. 5.4B

VALVE/ACTUATOR TRANSIENT RESPONSE

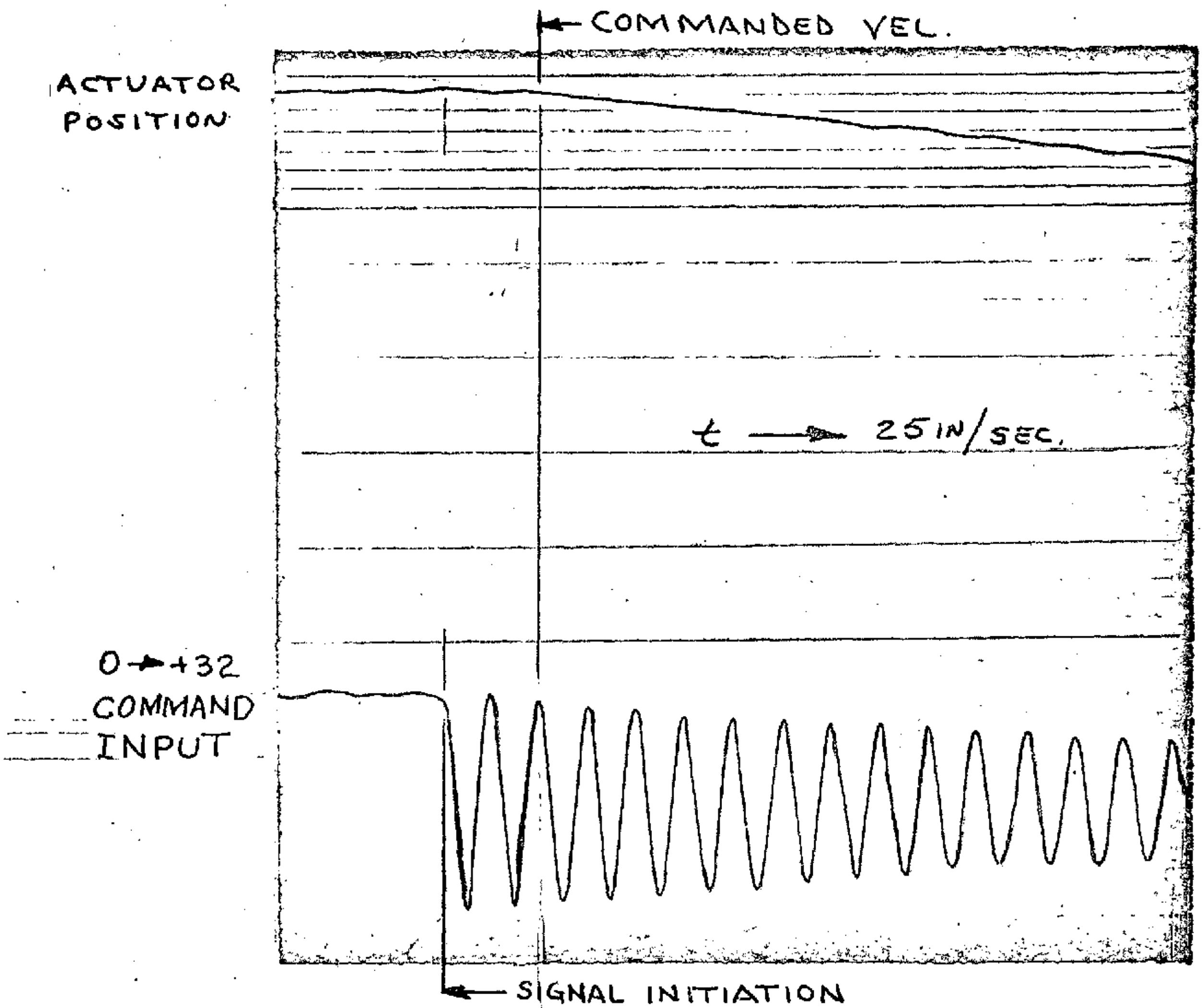


FIG. 5.4 C

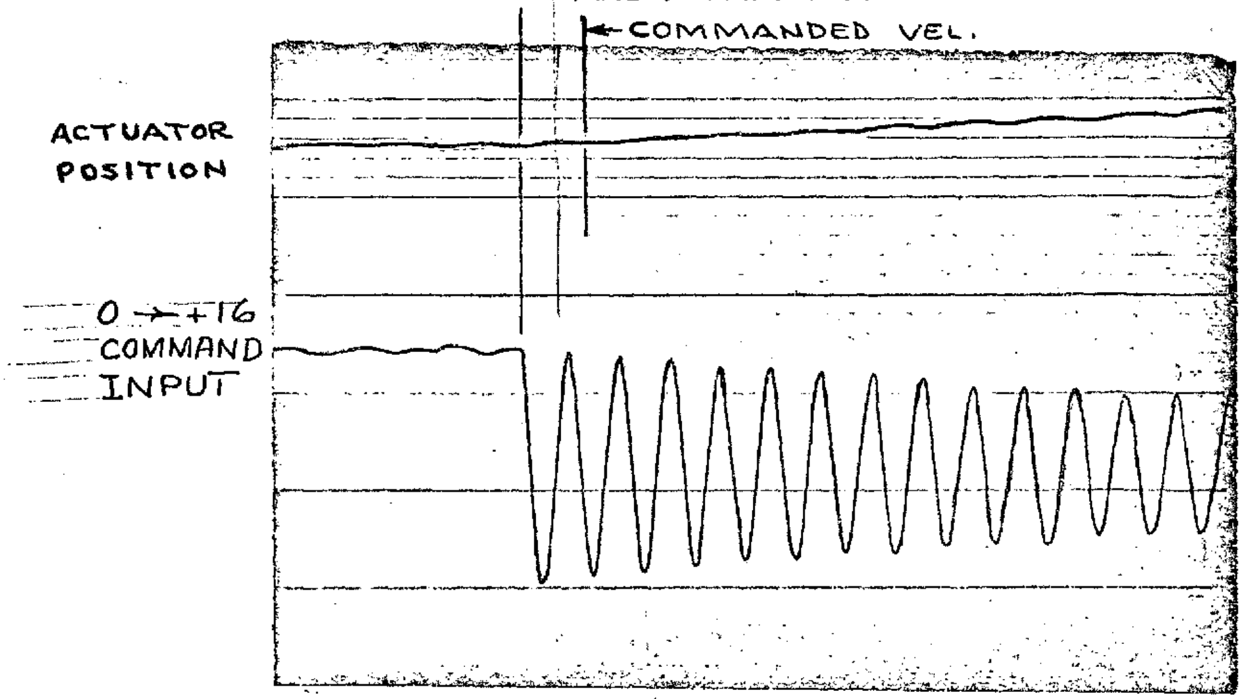


FIG. 5.4 D

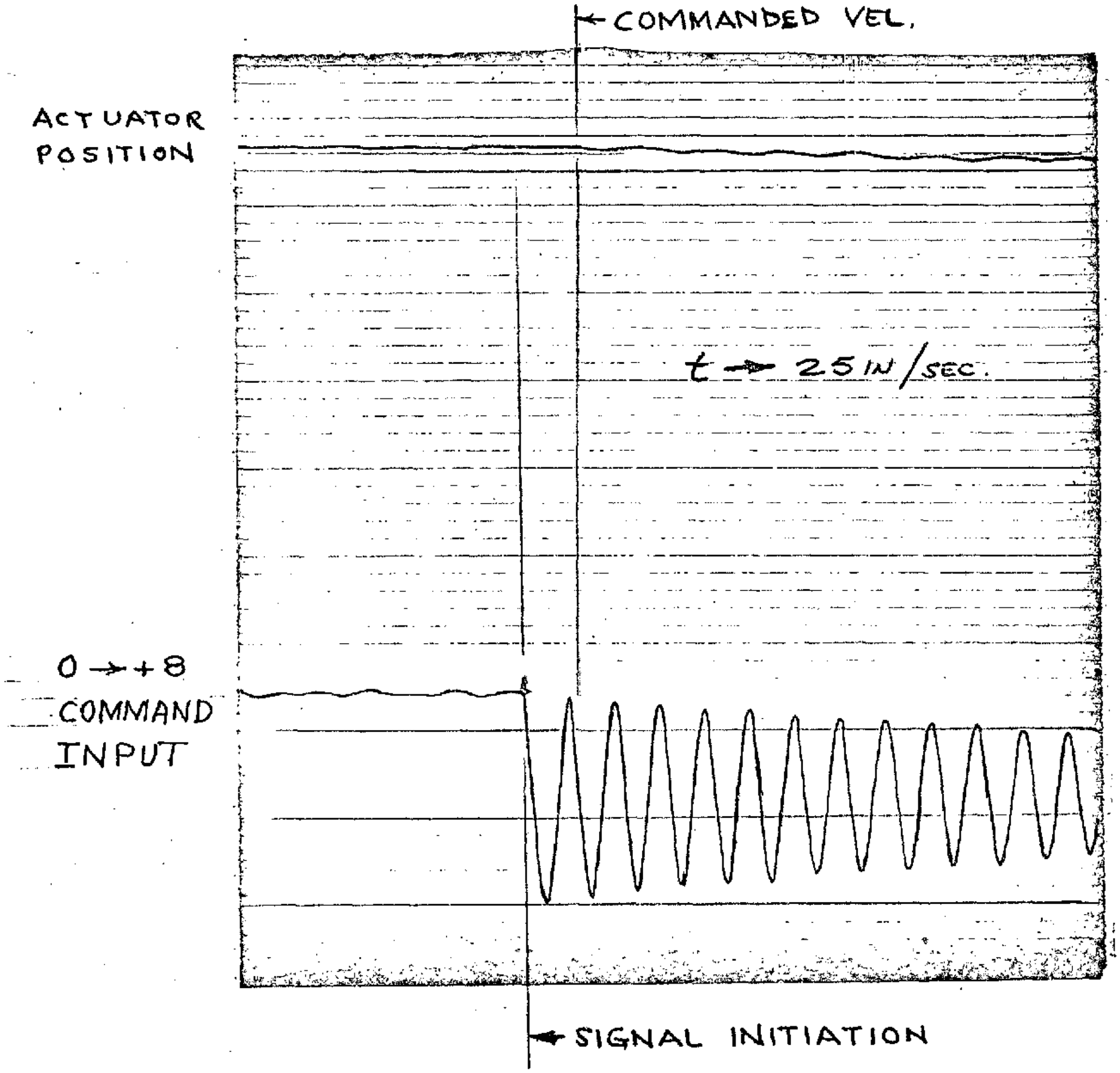

COMMANDED VEL.
ACTUATOR POSITION
t → 25 IN/SEC.
0 → +8 COMMAND INPUT
SIGNAL INITIATION

FIG. 5.4E

FREQUENCY RESPONSE DATA

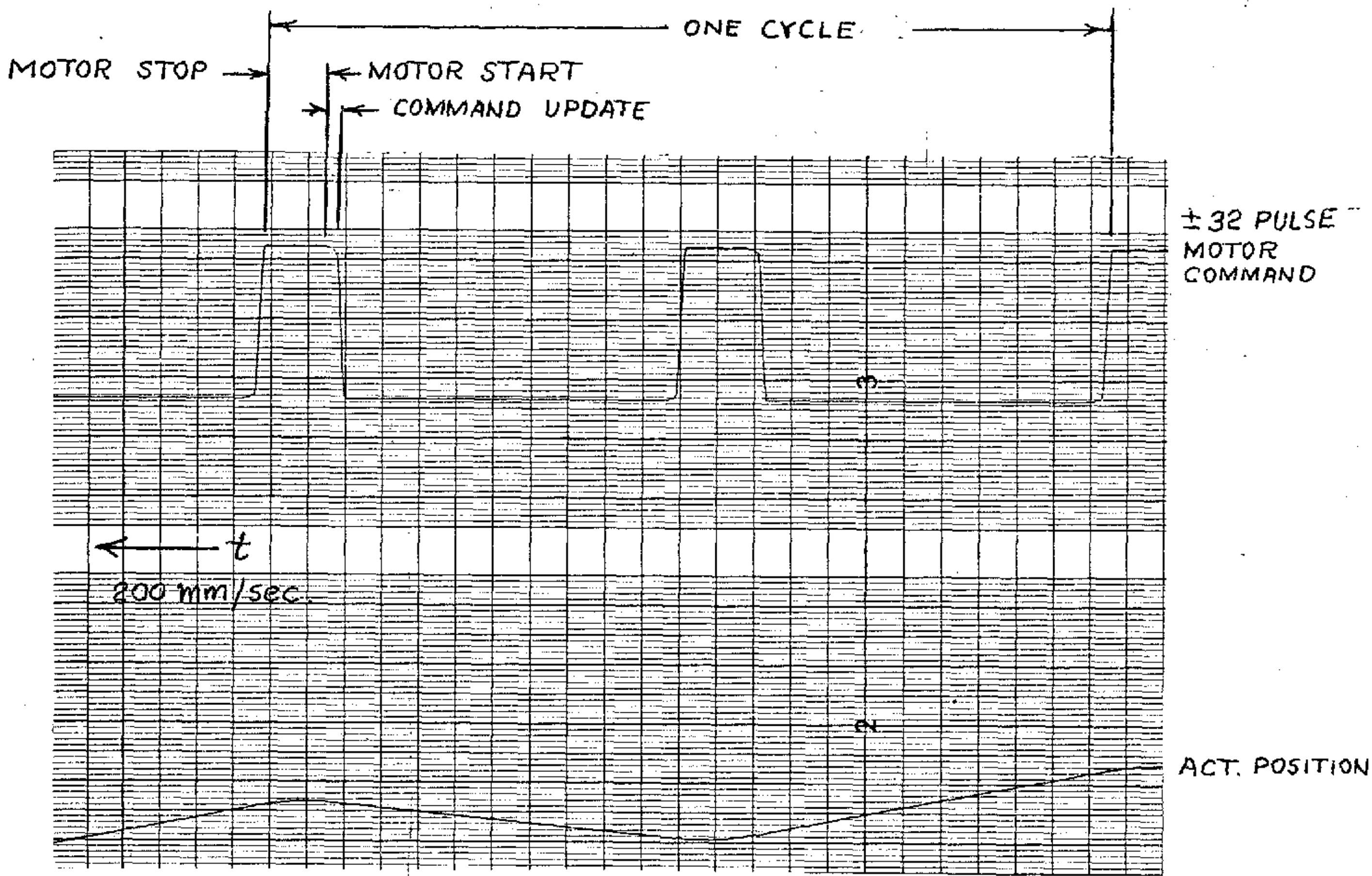


FIG. 5.4f

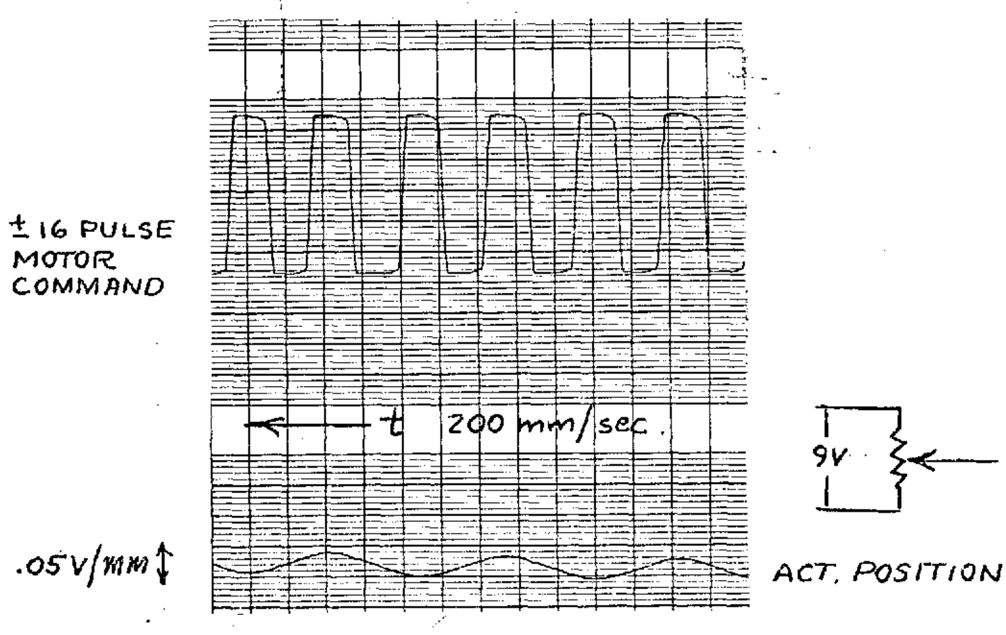


FIG. 5.4h

Input	Overall Valve/Act.	Motor Transport	Designed lag for command Update	Valve + Act. less Motor
± 32% rated @ 2 HZ	.057 sec.	.045 sec.	.007 sec.	.005 sec.
± 16% rated @ 10 HZ	.026	.020	.006	Approaches 0

This data shows that the valve responds fully to a command (as indicated by the constant velocity of the actuator) within a few milliseconds of the completion of the Stepper Motor positioning stroke.

Transient response traces were taken of the Stepper Motor driving a potentiometer (Computer Instrument Corp., Model 205) in place of the valve. These are shown on figures 5.4j, 5.4k, and 5.4m. This data is tabulated in the following table. Note that the "hash" appearing on the traces is predominantly due to pick-up that could not be prevented from getting into the recorder heads.

Motor Input Command	No. of Steps	Motor Starts After	Motor Stops After	Theoretical Motor Transport Time (1550 steps/sec)	Actual Deviation from transport time
+ 64 to 0	- 64	.004 sec.	.048 sec.	.042 sec.	.006
0 to + 96	+ 96	.004 sec.	.072	.062 sec.	.010
- 64 to + 64	+ 128	.004 sec.	.090	.083 sec.	.007

The actual motor transport time was greater than the theoretical due to the start-up lag time (.004 sec.) and the "settling" time during stopping. The latter is dependent upon the load inertia and friction, and also upon the relationship of the motor shaft to its rotating magnetic field at the time of stopping, which results in more or less overshoot. To observe this phenomenon more closely, the potentiometer trace was connected to an electronic "scope". A resulting trace is shown in figure 5.4n. The start time of the motor was observed to be between 2 and 3 milliseconds and the settling time was approximately 10 milliseconds. Since this "settling" time is actually associated with the potentiometer load (essentially zero frictional damping), it is felt that allowing a maximum of 10 milliseconds for settling time with the valve load should be conservatively adequate. Thus, with this assumption and using a pulse rate of 1600 steps per second, we can derive a curve showing the maximum frequency response of the present digital valve as a function

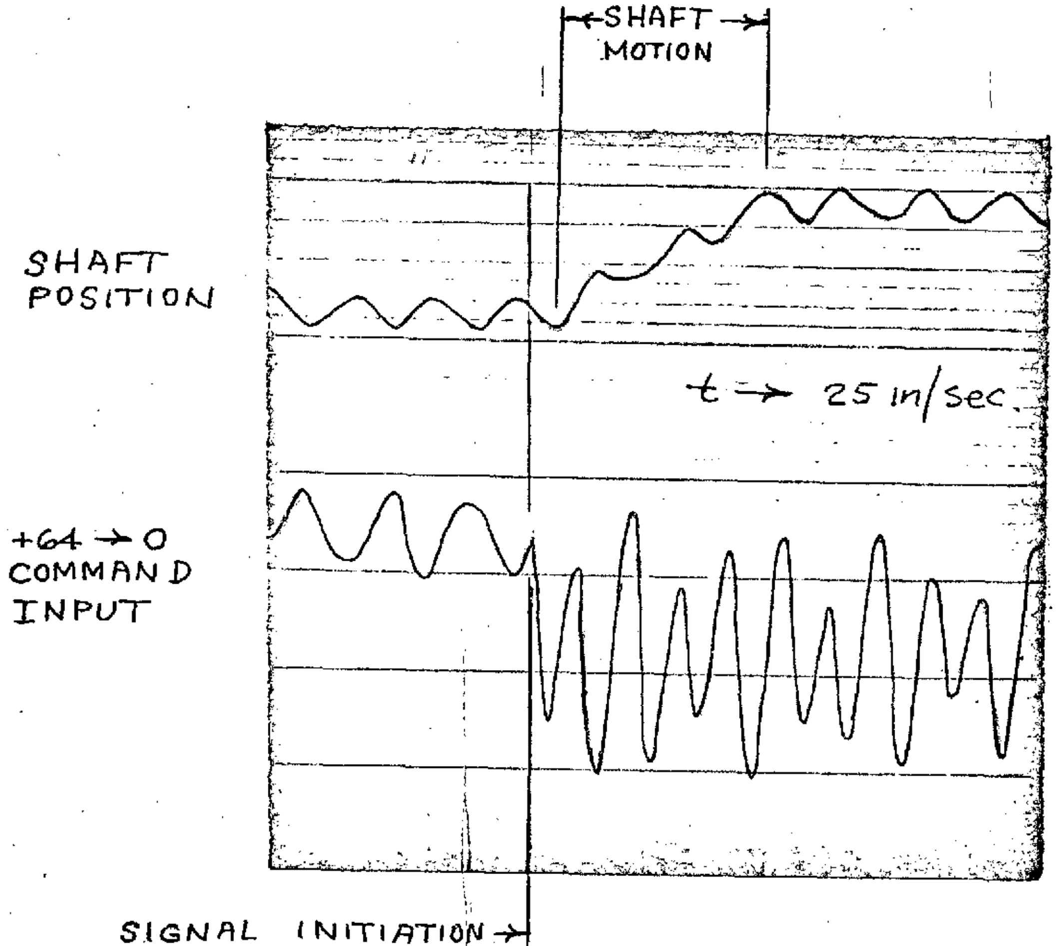


FIG. 5.4 J

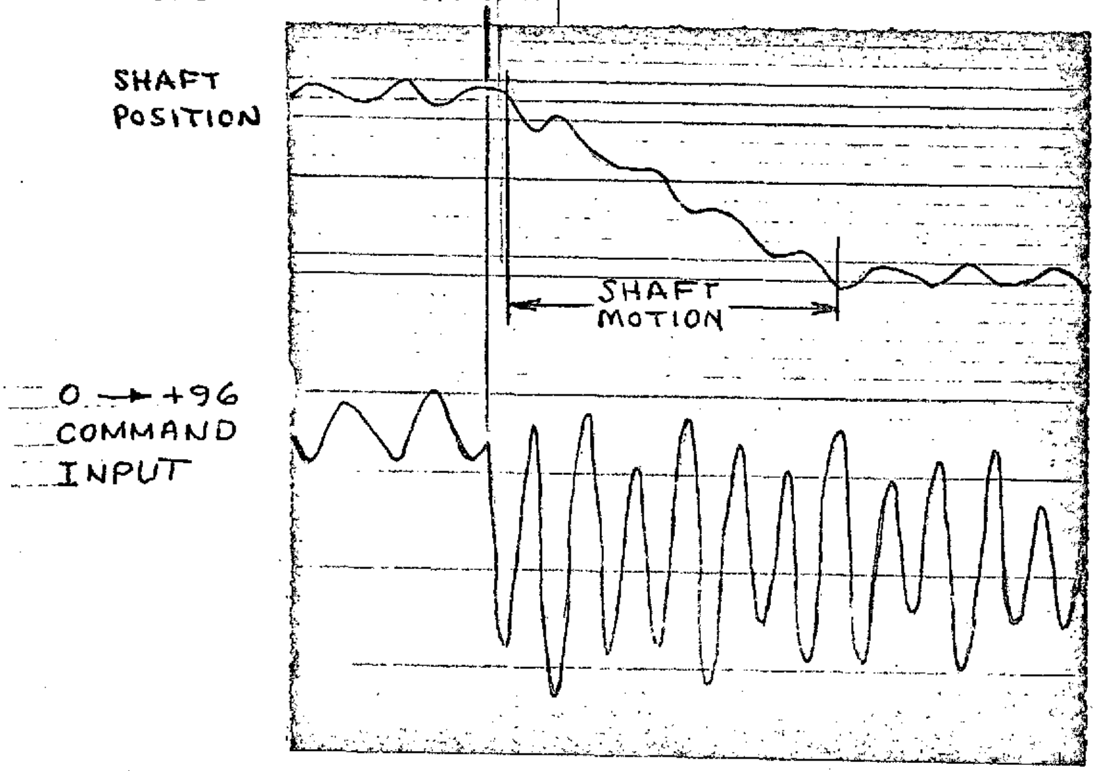


FIG. 5.4K

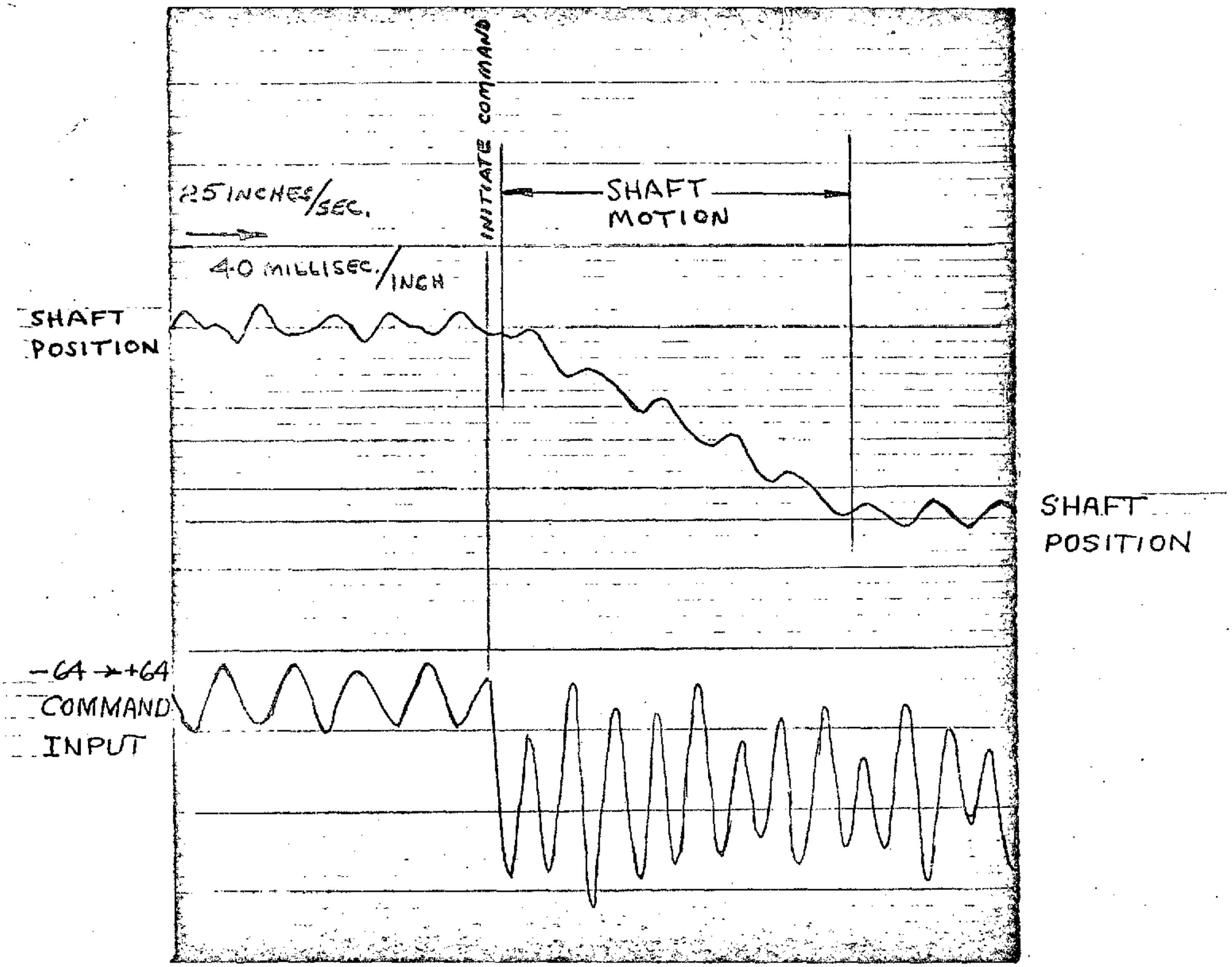

INITIATE COMMAND
2.5 INCHES/SEC.
4.0 MILLISEC./INCH
SHAFT MOTION
SHAFT POSITION
SHAFT POSITION
−64 → +64 COMMAND INPUT

FIG. 5.4M

REPRODUCTION OF OSCILLOSCOPE TRACE OF
STEPPER MOTOR DRIVING POTENTIOMETER
(MESUR-MATIC 2.75-100-1-8) (C.I.C. MODEL 205)

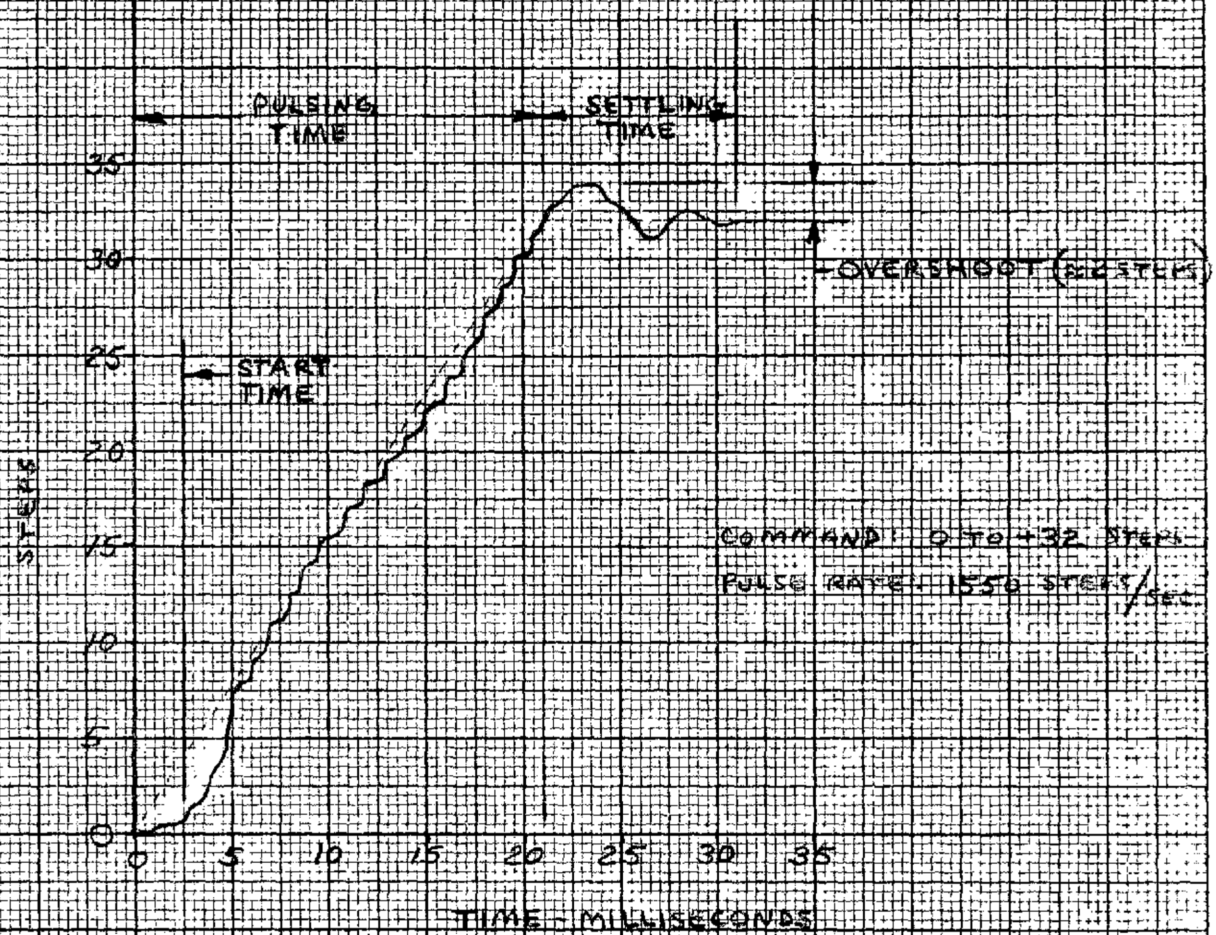


FIG. 5.4a

of flow rate magnitude. This curve is shown in figure 5.4p. From it we can deduce that for the conventional definition of frequency response (± 1/4 maximum amplitude) this digital valve in its present configuration has a response that is flat to 12 HZ.

5.5 QUIESCENT CONTROL POWER

A comparison of quiescent control power of this digital valve and a conventional servovalve of comparable flow capacity is useful. The standby electric power consumption of the digital motor is 7 1/2 amps at an average voltage of 28 V.D.C. (48 V.D.C. switched on-off at 6 kilo HZ). This represents 210 watts or 0.268 horsepower. Under zero flow conditions, a conventional servovalve would require no electrical power input. (This ignores the low power consumption of the electric amplifiers or logic circuits in each valve, which is about the same). First stage flow of the digital valve is 0.05 GPM while a conventional valve requires 0.156 GPM at 3000 psi. This data is tabulated in the following table.

Valve	Standby Electric Power	First Stage Hydraulic Power	Total Control Power
Digital	0.268 HP	0.086 HP	0.354 HP
Conventional	0	0.273	0.273

In both cases second stage leakage is not included. It should be approximately equal for both valves.

This comparison must be evaluated in the light of the fact that the electrical standby power is capable of being reduced substantially (see section 6, Reconnemdations), and the digital valve hydraulic quiescent power results in a driving force capability that is 5 times that of the equivalent conventional servovalve.

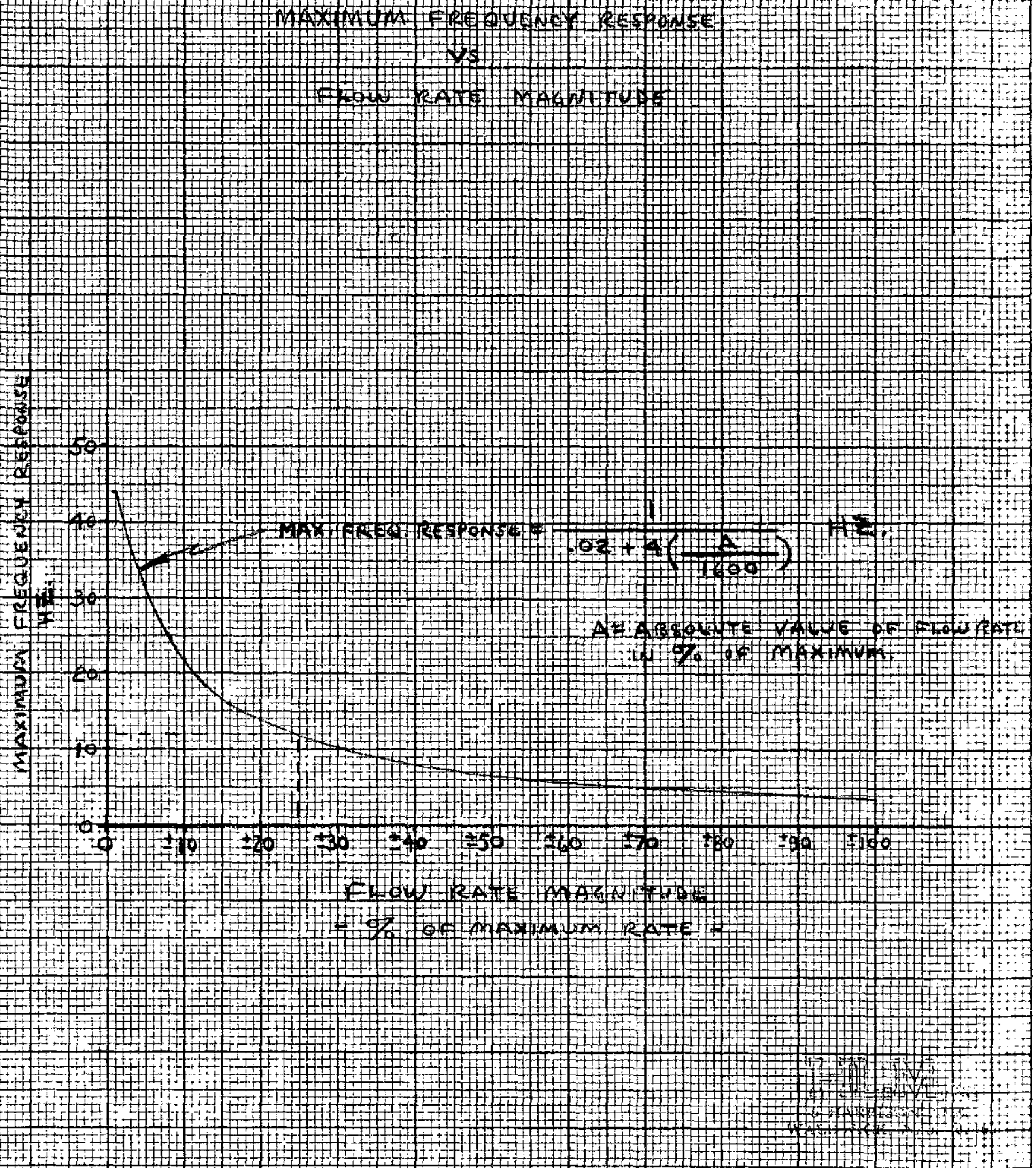

MAXIMUM FREQUENCY RESPONSE
VS
FLOW RATE MAGNITUDE
MAXIMUM FREQUENCY RESPONSE
HZ.
50
40
30
20
10
0
0
±10
±20
±30
±40
±50
±60
±70
±80
±90
±100
MAX. FREQ. RESPONSE = $\dfrac{1}{.02 + 4\left(\dfrac{A}{1600}\right)}$ HZ.
A = ABSOLUTE VALUE OF FLOW RATE IN % OF MAXIMUM.
FLOW RATE MAGNITUDE
– % OF MAXIMUM RATE –

FIG. 5.4p

6. RECOMMENDATIONS

This program has demonstrated the potential of the valving approach which utilizes the hydraulic helix. A continuation down this trail is warranted and could lead to further significant advances. With this in mind the following avenues are suggested for additional development.

1. Reduction of quiescent power.
2. Investigate null condition effect on performance.
3. Reduction of size of Stepper Motor package.
4. Investigate methods to improve dynamic response.
5. Provide mechanical feedback between valve and actuator.

6.1 QUIESCENT POWER

Reduction of quiescent power can be accomplished in two areas, hydraulic and electric. As discussed elsewhere in this report, by reducing the first stage spool null underlap, the quiescent hydraulic flow can be made to approach zero.

The greatest reduction in quiescent power can be realized by reduction of standby power to the Stepper Motor. This could be accomplished by incorporating a simple circuit that is available from the Stepper Motor supplier. A signal from the logic circuit is required to indicate that the valve is in a non-stepping mode. Such a signal is available from our control circuit at the Comparator A = B terminal (see figure 3.2a). The electrical standby power savings that could be realized is approximately 100 watts (0.13 HP) approximately half of its present value.

6.2 NULL CUT AND PERFORMANCE

While this Digital Valve has very good hysteresis characteristics (less than 1%), it can be improved further. The first stage null underlap can be reduced. This would reduce the quiescent hydraulic power requirements, as discussed in section 6.1 above. And it would also increase pressure gain and reduce even further the low valve hysteresis. The first stage flow would be limited by the reduction in null underlap, which might affect hydraulic dynamic response. However, it has been demonstrated by this program that limitations on response occur at the Stepper Motor. Thus, reduction of null underlap should result in advantages of lower quiescent power requirements and reduced hysteresis, while not appreciably diminishing dynamic response of the overall valve package.

6.3 REDUCE STEPPER MOTOR SIZE

Aside from providing a possible reduction in standby power, a smaller Stepper Motor would reduce the valve envelope size. A smaller motor is potentially available. It should require approximately 20% less electrical power and produce 33% of the output torque, which would still be adequate for this application. Also, the internal motor inertia should be greatly reduced, thus allowing for higher start-stop stepping rates, which could enhance dynamic performance.

6.4 IMPROVING DYNAMIC RESPONSE

If frequency response is to be increased, the valve driving unit (Stepper Motor in this case) must be improved. Any rotary positioner can be used to drive the valve input shaft, such as a D.C. motor. But the Stepper Motor drive does have the advantage of being compatible with direct digital input circuitry. The Stepper Motor used in this study can be improved by adding another circuit card equivalent in size and complexity to the Mesur-Matic DD-6 circuit. This additional circuit has the capability of receiving and storing input pulses at a constant rate. It releases these pulses at a controlled accelerating rate and then, at the conclusion of the input pulses, at a controlled decelerating rate. The net result is to keep the load synchronized with the pulses to the Stepper Motor so that it can be positioned at a greater slew rate, resulting in a faster average positioning rate with little overshoot and a minimum of settling time. This approach calls for a trade-off between additional circuit complexity and increased dynamic response. Theoretical evaluation of such a circuit addition indicates that frequency response could be improved by about 50%.

Another approach to this dynamic response limitation is to allow the valve to control the system with regard to the rate of command signal up-dating. The circuit as it exists has the capability of signalling the external control system as to when it is ready for a new command. The worst case is the time to respond to a "hard-over to hard-over" signal (200 steps) at the 1550 steps/sec. rate. This response would take approximately 140 milliseconds allowing for settling time. A signal could subsequently be initiated to return the valve to its original "hard-over" position in an additional 140 milliseconds. This is equivalent to a flat frequency response of 3 1/2 HZ at ± full amplitude. This mode of operation is readily mechanized with the existing hardware as delivered. The actual frequency response capability of the valve for a particular signal amplitude is shown in figure 5.4p (3 1/2 HZ to 44 HZ). This concept of operation is only applicable to systems that can tolerate the worst case of command response time of 140 milliseconds.

The hydraulic portion of this valve has been developed to the point where the specifications for a digital driver of the valve can be defined. This should be considered the starting point for the derivation of new concepts in a low inertia drive that could accept digital inputs.

6.5 MECHANICAL FEEDBACK

When considering servovalve and actuator as a package, a logical extension of this program would be to provide mechanical feedback from actuator to valve. This valve approach does lend itself to such an arrangement. The relative simplicity and reliability of such a combination could provide a significant advance in the state-of-the-art. The overall valve-actuator package would be fed a digital word command that would represent a discrete actuator position, with the feedback being provided mechanically within the package itself.

7. DRAWING TABULATION

The following is a list of drawings prepared in performing tasks of this program.

1231-1	Layout, Valve
1231-2	Layout, Null Fixture
2485	Control Circuit - Stepper Motor with Position Encoder
2486 Revision A	Control Circuit - Stepper Motor with Up-Down Counter
2517	Control Circuit - Summing Output with Reversing Valve
2627	Spool/Sleeve Assembly
2628 Revision A	Sleeve
2629	Spool, Power, Pre-Null
2630	Spool, Input, Pre-Null
2631	Spool, Input Blank
2632	Plug
2633	End Cap
2634	Pin, Key
2635	End Cap, Mount
2658	Body
2664	Motor, Pulse
2678	Adapter, Actuator
2679	Manifold, Test
2680	End Cap, Null Fixture
2681	Adjustor, Null Fixture
2682	Plug, Null Fixture
2683	Plug, Null Fixture
2684	Plug, Null Fixture
2685	Mount, Null Fixture
2686	Spacer, Null Fixture
2687	Fitting, Null Fixture
2894	Inverter/Driver Logic Card, Modified
2895	Valve Assembly
2896	Electric Control Assembly
2898	Multi-Vibrator Logic Card, Modified
2900	Coupling
2918	Control Circuit - Stepper Motor with Up-Down Counter
	Parts List Model 1231 Digital Hydraulic Valve
	Parts List Model 1231 Control Circuit for Digital Hydraulic Valving System
	Parts List Model 1231-2 Test Fixtures
	Parts List Model 1231-3 Electrical Test Equipment
780-2609	Up-Down Binary Counter
780-2834 Sheets 1 & 2	Shift Register
780-3409	Parallel Binary Comparator
780-5909	Free Running Multivibrator

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DIGITAL HYDRAULIC VALVING SYSTEM - CONTRACT NAS 8-28166

Electrical Control Circuit - Operating Procedure (Revised August 6, 1973)

Reference: Control Circuit - HLM, Inc. Drawing Number 2918
Electrical Control Assembly - HLM, Inc. Drawing Number 2896

A. INTRODUCTION

The Electrical Control Assembly shown on HLM, Inc. drawing number 2896 contains all the electronic components needed to control the Stepper Motor and Valve Assembly. The latter is connected to the Control Assembly by means of a 10 wire cable, with a disconnecting plug at the motor (J-1; P-1) and a terminal strip at the Control Assembly (external terminals 1 through 10).

Power for the Control Assembly is as follows:

a) Standard 115 V.A.C., 60 HZ, single phase for the Blower Motor.

b) Regulated 5 V.D.C., to plug P-2; this is for logic circuits and the negative side of the 5 V.D.C. is grounded to the cabinet and chassis.

c) Unregulated 48 V.D.C., to plug P-3; this is for the motor drive circuit. Note that both the positive and negative sides of this 48 V.D.C. supply must be insulated from ground. A separate ground terminal is provided in the plug for grounding the associated shield.

For convenience, a power supply for the above mentioned voltages is provided by the HLM, Inc. power unit Model 1231-3. This unit has an On-Off toggle switch that controls all three voltages. With this switch in the Off position, plug the unit's line cord into a 115 V.A.C., 60 HZ, 10 amp. max. single phase power source. Plug the Blower Motor line cord into the receptacle provided on the power unit. Also insert the cable jacks J-2 and J-3 into the appropriate plugs on the back of the Electrical Control Assembly. Connect the Stepper Motor to its cable connector (J-1; P-1) and check to see that the opposite end of this cable is securely connected to the terminal strip at the Control Assembly. Now the unit is ready for operation.

B. START - UP

Having made all the connections alluded to above in section "A", the Stepper Motor-Valve Assembly must be oriented so that the valve is approximately at null (zero flow). This can be accomplished as follows:

1. Loosen the shaft coupling at the Stepper Motor.
2. On the rear of the Control Assembly, place all four "Input" switches in the "Manual" position, and place all eight binary "Selection" switches (1, 2, 4 .... 128) in the "Off" or "O" position.
3. Lift the top hinged cover of the Control Assembly and place the "Enable Mode" switch in Manual/External position.
4. Turn "On" the power supply; this will start the blower running.
5. Press the "Motor Phase Reset" pushbutton on the front panel; this will orient the Stepper Motor so that its phases 1, 2 and 3 will be energized.
6. Press the "Counter Reset" pushbutton within the Control Assembly. Now both the motor and its Up-Down counter are at zero.
7. Manually turn the valve stem via the loose shaft coupling until the null position (zero flow) is indicated hydraulically. At this position tighten the coupling back into the Stepper Motor shaft. If a more accurate null is desired, loosen the 4 screws that secure the Stepper Motor to the Valve Flange. Rotating the motor relative to this flange will result in more accurate control of the null point. Now the unit is ready for controlling flow.

C. MANUAL OPERATION

1. Manually set-up a digital command by means of the slide switches in the rear of the Control Assembly. The four "Input" switches must remain in the "Manual" position. Reference the attached chart (Binary Coded Equivalent of Digital Values). This shows the position that each of the eight binary "Selection" switches should have for a given command; "1" means "On", that is, the switch slide "Up"; "O" means "Off", that is, the switch slide "Down".

2. When the command has been set-up per the foregoing, pressing the "Manual Stepper Motor Enable" switch (red) on the front panel will cause the Motor to position the valve to the corresponding flow rate. This switch must be held actuated until the motor has stopped. This should take place in less than 1/8 of a second (for 200 step stroke).

D. SEMI-AUTOMATIC OPERATION

Automatic cycling can be provided to a limited degree using a square wave source of voltage (0 to 5 V.D.C.) which can be started and stopped, but only if the time duration of the state (0 or 5 V.D.C.) preceding the stop command is allowed to continue for at least its normal period of time, that is, its cycle time. This can be accomplished easily with an electromechanical pulse generator. One version consists of a 115 V.A.C. small gear motor whose shaft is rotating at 2 revolutions per second. By attaching coded disks to this shaft so that an optical coupled electrical circuit may be interrupted at a rate determined by the shaft speed and the number of lobes on the disk, a signal generator having the properties alluded to above is created. HLM, Inc. used such a device to cycle the system at rates of 2 HZ, 4 HZ and 10 HZ (using three separate coded interruptor disks). This arrangment uses an Optical Switch Kit (OS-591S-200 LW). Three wires from this switch are connected to "5 volt positive" terminal (#14), "5 volts negative" terminal (#13), and to the internal terminal (#16) for cycling. Reference to the Control Circuit drawing number 2918 will reveal that this feature works in conjunction with the "Input" switches (located on rear of Control Assembly). When an "Input switch corresponding to any bit (128, 64, 32 or 16) is in the "External" position, then that bit input to the Comparitor circuit is dependent upon the signal at the internal terminal #16 (and is essentially inverted by associated Buffer/Driver located between internal terminals #16 and #11, so that a signal greater than 3.3 V.D.C. at terminal #16 corresponds to a "0" bit, and a signal less than 0.6 V.D.C. corresponds to a "1" bit).

The procedure for using this feature to input commands of +8, followed by -8, then back to +8, etc.; or to input commands of +16, followed by -16, then back to +16, etc.; or to input similar alternating commands of ± 32 or ± 64, is as follows:

1. Set-up the system as outlined above for Manual Operation to the desired positive (+) command (8, 16, 32 or 64).

2. Rotate the coded disk of the electromechanical signal generator in position to interrupt the Optical switch.

3. Position all the "Input" switches associated with all binary values greater than the desired command to the "External" position. An example is: if a command of ± 16 is desired, the "Input" switches corresponding to bits 128, 64 and 32 should be placed in the "External" position.

4. Lift the top hinged cover of the Control Assembly and place the "Enable Mode" switch in "Auto" position.

5. Now the unit is ready for cycling between the plus and minus values of the command selected.

It should be noted that when stopping the cycle, the coded disk should once again be placed so as to interrupt the Optical switch. Now the "Enable Mode" switch can be returned to "Manual", the "Input" switches returned to "Manual" position, and manual operation to a new command executed, if desired.

BINARY CODED EQUIVALENTS OF DIGITAL VALUES: Negative Numbers are in "Two's Complement" form

NEGATIVE (-) 128	64	32	16	8	4	2	1	Digital	POSITIVE (+) 128	64	32	16	8	4	2	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1
1	1	1	1	1	1	1	0	2	0	0	0	0	0	0	1	0
1	1	1	1	1	1	0	1	3	0	0	0	0	0	0	1	1
1	1	1	1	1	1	0	0	4	0	0	0	0	0	1	0	0
1	1	1	1	1	0	1	1	5	0	0	0	0	0	1	0	1
1	1	1	1	1	0	1	0	6	0	0	0	0	0	1	1	0
1	1	1	1	1	0	0	1	7	0	0	0	0	0	1	1	1
1	1	1	1	1	0	0	0	8	0	0	0	0	1	0	0	0
1	1	1	1	0	1	1	1	9	0	0	0	0	1	0	0	1
1	1	1	1	0	1	1	0	10	0	0	0	0	1	0	1	0
1	1	1	1	0	1	0	1	11	0	0	0	0	1	0	1	1
1	1	1	1	0	1	0	0	12	0	0	0	0	1	1	0	0
1	1	1	1	0	0	1	1	13	0	0	0	0	1	1	0	1
1	1	1	1	0	0	1	0	14	0	0	0	0	1	1	1	0
1	1	1	1	0	0	0	1	15	0	0	0	0	1	1	1	1
1	1	1	1	0	0	0	0	16	0	0	0	1	0	0	0	0
1	1	1	0	1	1	1	1	17	0	0	0	1	0	0	0	1
1	1	1	0	1	1	1	0	18	0	0	0	1	0	0	1	0
1	1	1	0	1	1	0	1	19	0	0	0	1	0	0	1	1
1	1	1	0	1	1	0	0	20	0	0	0	1	0	1	0	0
1	1	1	0	1	0	1	1	21	0	0	0	1	0	1	0	1
1	1	1	0	1	0	1	0	22	0	0	0	1	0	1	1	0
1	1	1	0	1	0	0	1	23	0	0	0	1	0	1	1	1
1	1	1	0	1	0	0	0	24	0	0	0	1	1	0	0	0
1	1	1	0	0	1	1	1	25	0	0	0	1	1	0	0	1
1	1	1	0	0	1	1	0	26	0	0	0	1	1	0	1	0
1	1	1	0	0	1	0	1	27	0	0	0	1	1	0	1	1
1	1	1	0	0	1	0	0	28	0	0	0	1	1	1	0	0
1	1	1	0	0	0	1	1	29	0	0	0	1	1	1	0	1
1	1	1	0	0	0	1	0	30	0	0	0	1	1	1	1	0
1	1	1	0	0	0	0	1	31	0	0	0	1	1	1	1	1
1	1	1	0	0	0	0	0	32	0	0	1	0	0	0	0	0
1	1	0	1	1	1	1	1	33	0	0	1	0	0	0	0	1
1	1	0	1	1	1	1	0	34	0	0	1	0	0	0	1	0
1	1	0	1	1	1	0	1	35	0	0	1	0	0	0	1	1
1	1	0	1	1	1	0	0	36	0	0	1	0	0	1	0	0
1	1	0	1	1	0	1	1	37	0	0	1	0	0	1	0	1
1	1	0	1	1	0	1	0	38	0	0	1	0	0	1	1	0
1	1	0	1	1	0	0	1	39	0	0	1	0	0	1	1	1
1	1	0	1	1	0	0	0	40	0	0	1	0	1	0	0	0
1	1	0	1	0	1	1	1	41	0	0	1	0	1	0	0	1
1	1	0	1	0	1	1	0	42	0	0	1	0	1	0	1	0
1	1	0	1	0	1	0	1	43	0	0	1	0	1	0	1	1
1	1	0	1	0	1	0	0	44	0	0	1	0	1	1	0	0
1	1	0	1	0	0	1	1	45	0	0	1	0	1	1	0	1
1	1	0	1	0	0	1	0	46	0	0	1	0	1	1	1	0
1	1	0	1	0	0	0	1	47	0	0	1	0	1	1	1	1
1	1	0	1	0	0	0	0	48	0	0	1	1	0	0	0	0
1	1	0	0	1	1	1	1	49	0	0	1	1	0	0	0	1
1	1	0	0	1	1	1	0	50	0	0	1	1	0	0	1	0

"1" = on = +5 volts D.C. Nominal (+3.3 volts min.)
"0" = off = 0 volts D.C. Nominal (0.6 volts max.)

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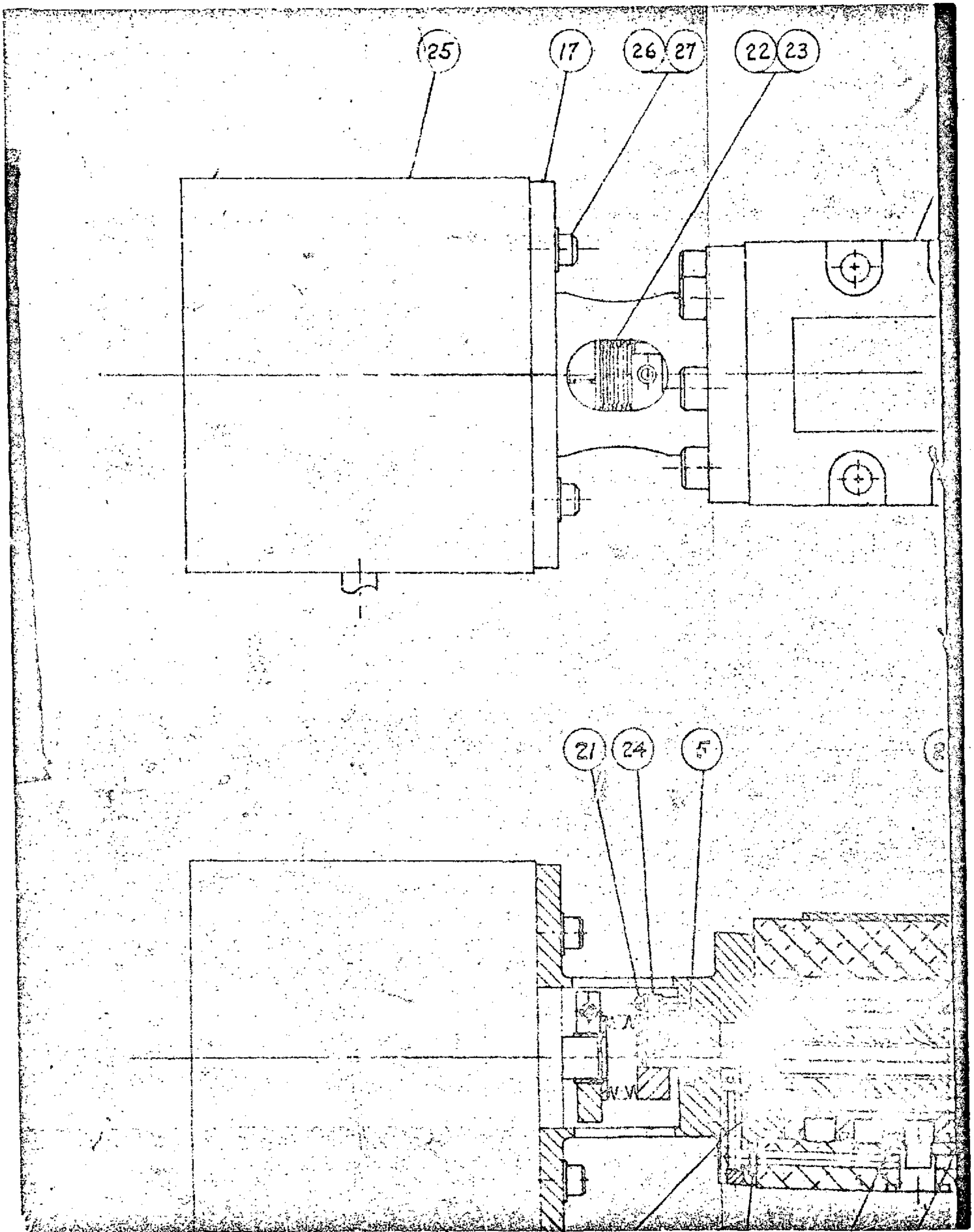
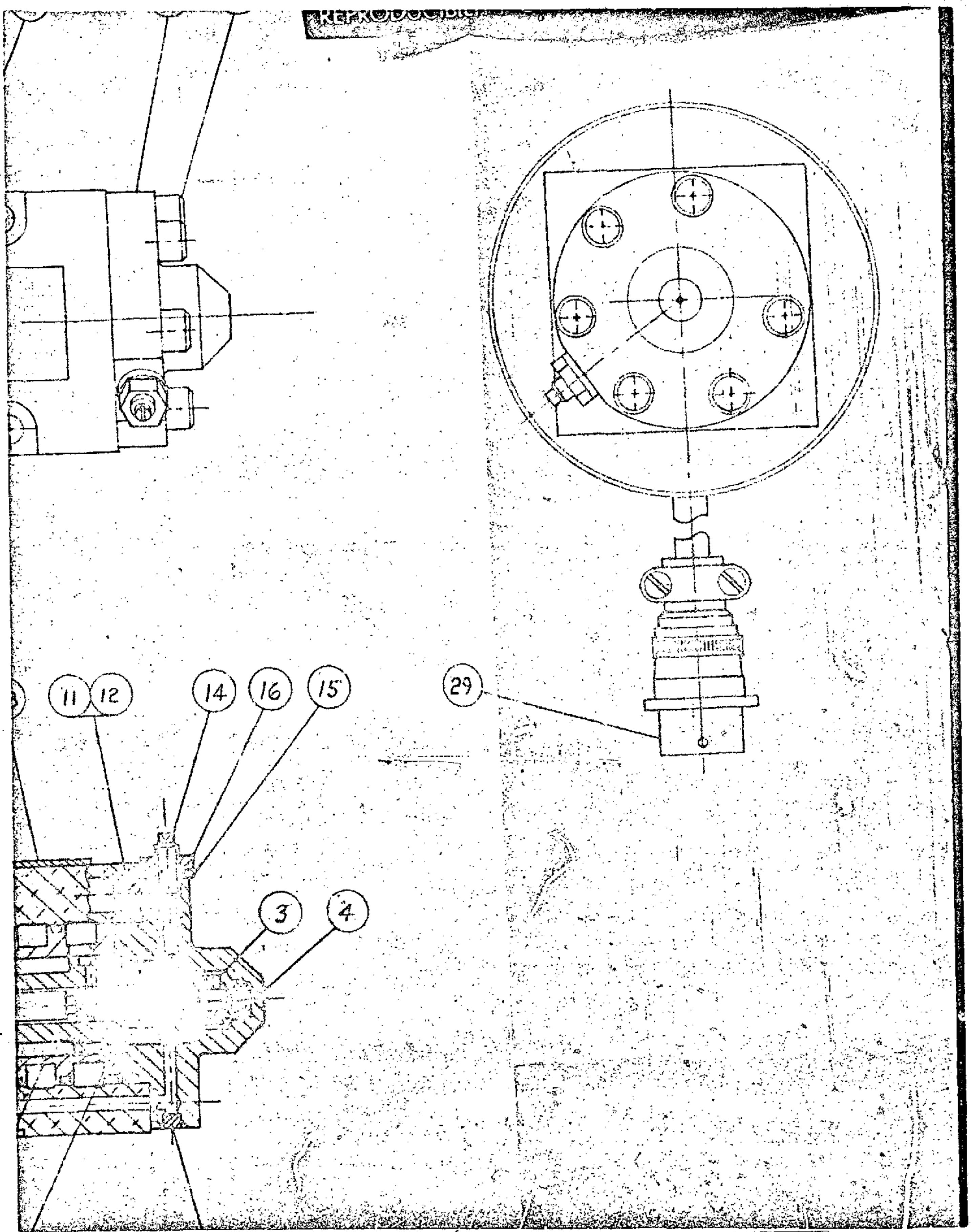
BINARY CODED EQUIVALENTS OF DIGITAL VALUES: Negative Numbers are in "Two's Complement" form

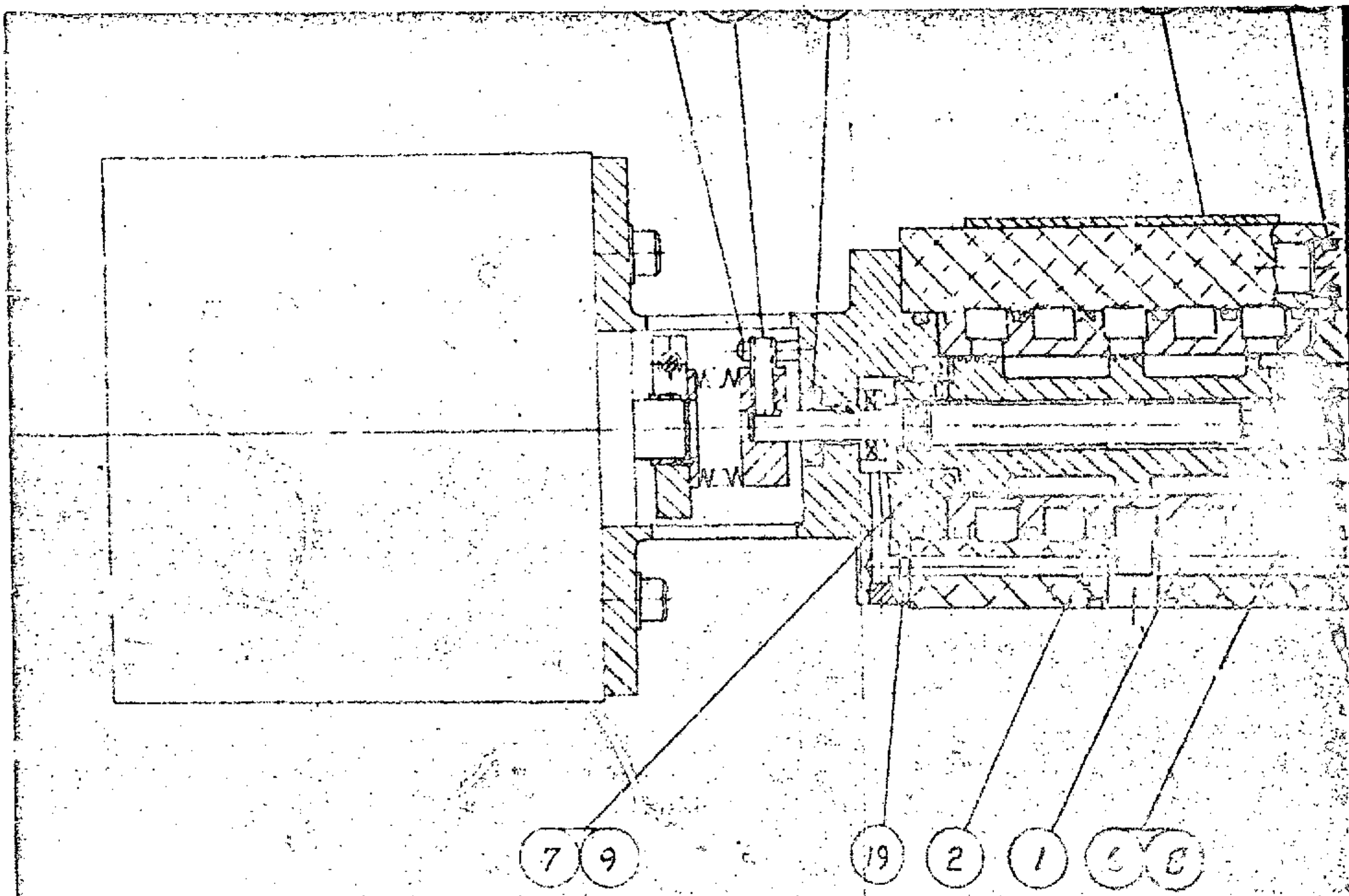
NEGATIVE (-) 128	64	32	16	8	4	2	1	Digital	POSITIVE (+) 128	64	32	16	8	4	2	1
1	1	0	0	1	1	0	1	51	0	0	1	1	0	0	1	1
1	1	0	0	1	1	0	0	52	0	0	1	1	0	1	0	0
1	1	0	0	1	0	1	1	53	0	0	1	1	0	1	0	1
1	1	0	0	1	0	1	0	54	0	0	1	1	0	1	1	0
1	1	0	0	1	0	0	1	55	0	0	1	1	0	1	1	1
1	1	0	0	1	0	0	0	56	0	0	1	1	1	0	0	0
1	1	0	0	0	1	1	1	57	0	0	1	1	1	0	0	1
1	1	0	0	0	1	1	0	58	0	0	1	1	1	0	1	0
1	1	0	0	0	1	0	1	59	0	0	1	1	1	0	1	1
1	1	0	0	0	1	0	0	60	0	0	1	1	1	1	0	0
1	1	0	0	0	0	1	1	61	0	0	1	1	1	1	0	1
1	1	0	0	0	0	1	0	62	0	0	1	1	1	1	1	0
1	1	0	0	0	0	0	1	63	0	0	1	1	1	1	1	1
1	1	0	0	0	0	0	0	64	0	1	0	0	0	0	0	0
1	0	1	1	1	1	1	1	65	0	1	0	0	0	0	0	1
1	0	1	1	1	1	1	0	66	0	1	0	0	0	0	1	0
1	0	1	1	1	1	0	1	67	0	1	0	0	0	0	1	1
1	0	1	1	1	1	0	0	68	0	1	0	0	0	1	0	0
1	0	1	1	1	0	1	1	69	0	1	0	0	0	1	0	1
1	0	1	1	1	0	1	0	70	0	1	0	0	0	1	1	0
1	0	1	1	1	0	0	1	71	0	1	0	0	0	1	1	1
1	0	1	1	1	0	0	0	72	0	1	0	0	1	0	0	0
1	0	1	1	0	1	1	1	73	0	1	0	0	1	0	0	1
1	0	1	1	0	1	1	0	74	0	1	0	0	1	0	1	0
1	0	1	1	0	1	0	1	75	0	1	0	0	1	0	1	1
1	0	1	1	0	1	0	0	76	0	1	0	0	1	1	0	0
1	0	1	1	0	0	1	1	77	0	1	0	0	1	1	0	1
1	0	1	1	0	0	1	0	78	0	1	0	0	1	1	1	0
1	0	1	1	0	0	0	1	79	0	1	0	0	1	1	1	1
1	0	1	1	0	0	0	0	80	0	1	0	1	0	0	0	0
1	0	1	0	1	1	1	1	81	0	1	0	1	0	0	0	1
1	0	1	0	1	1	1	0	82	0	1	0	1	0	0	1	0
1	0	1	0	1	1	0	1	83	0	1	0	1	0	0	1	1
1	0	1	0	1	1	0	0	84	0	1	0	1	0	1	0	0
1	0	1	0	1	0	1	1	85	0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0	86	0	1	0	1	0	1	1	0
1	0	1	0	1	0	0	1	87	0	1	0	1	0	1	1	1
1	0	1	0	1	0	0	0	88	0	1	0	1	1	0	0	0
1	0	1	0	0	1	1	1	89	0	1	0	1	1	0	0	1
1	0	1	0	0	1	1	0	90	0	1	0	1	1	0	1	0
1	0	1	0	0	1	0	1	91	0	1	0	1	1	0	1	1
1	0	1	0	0	1	0	0	92	0	1	0	1	1	1	0	0
1	0	1	0	0	0	1	1	93	0	1	0	1	1	1	0	1
1	0	1	0	0	0	1	0	94	0	1	0	1	1	1	1	0
1	0	1	0	0	0	0	1	95	0	1	0	1	1	1	1	1
1	0	1	0	0	0	0	0	96	0	1	1	0	0	0	0	0
1	0	0	1	1	1	1	1	97	0	1	1	0	0	0	0	1
1	0	0	1	1	1	1	0	98	0	1	1	0	0	0	1	0
1	0	0	1	1	1	0	1	99	0	1	1	0	0	0	1	1
1	0	0	1	1	1	0	0	100	0	1	1	0	0	1	0	0

"1" = on = +5 volts D.C. Nominal (+3.3 volts min.)
"0" = off = 0 volts D.C. Nominal (0.6 volts max.)

HLM INC.
5 HARRISON AVE.
WALDWICK, N. J. 07463


25
17
26
27
22
23
21
24
5


11
12
14
16
15
29
3
4



NOTES:
1. BOND NAMEPLATE ITEM 28 TO BODY ITEM 10.
2. ADJUST KEY ITEM 14 FOR ZERO BACKLASH.

DOUT FRAME

2

		CONNECTOR BEND. PT-01A-12-10P-SR	29
1		NAMEPLATE	28
4		FLAT WASHER #8	27
4		SCREW #8-32 SHCS × 5/8 LG.	26
1	2664	MOTOR, PULSE	25
1		SCREW, SET #8-32 × 1/2 LG.	24
1		CLAMP ECONALIGN GC-15-9	23
1	2900	COUPLING	22
2		PIN, DOWEL 1/8 DIA. × 5/8 LG.	21
12		SCREW, 1/4-20 SHCS × 3/4 LG	20
2		O-RING MS28775-00[illegible]	19
2		PLUG LEE 156002	18
1	2635	END CAP, MOUNT	17
1		NUT, HEX #10-32	16
1		STATOSEAL #10	15
1	2634	PIN, KEY	14
1	2633	END CAP	13
1		O-RING MS28775-009	12
1	2632	PLUG	11
1	2658	BODY	10
[illegible]		GLYD RING SHAMBAM S12066-015N	9
[illegible]		GLYD RING SHAMBAM S12063-016N	8
		O-RING MS28775-018	7
		O-RING MS28775-015	6
		SEAL, SHAFT C/R 1250	5
		SPRING ASSOC. C0000-025-0880M	4
		BEARING, THRUST GBFT-01	3
		O-RING MS28775-027	2
	[illegible]27	SPOOL/SLEEVE ASSY.	1
		DESCRIPTION	ITEM NO.

FOLDOUT FRAME 4

HLM [illegible] WALDWICK NEW JERSEY

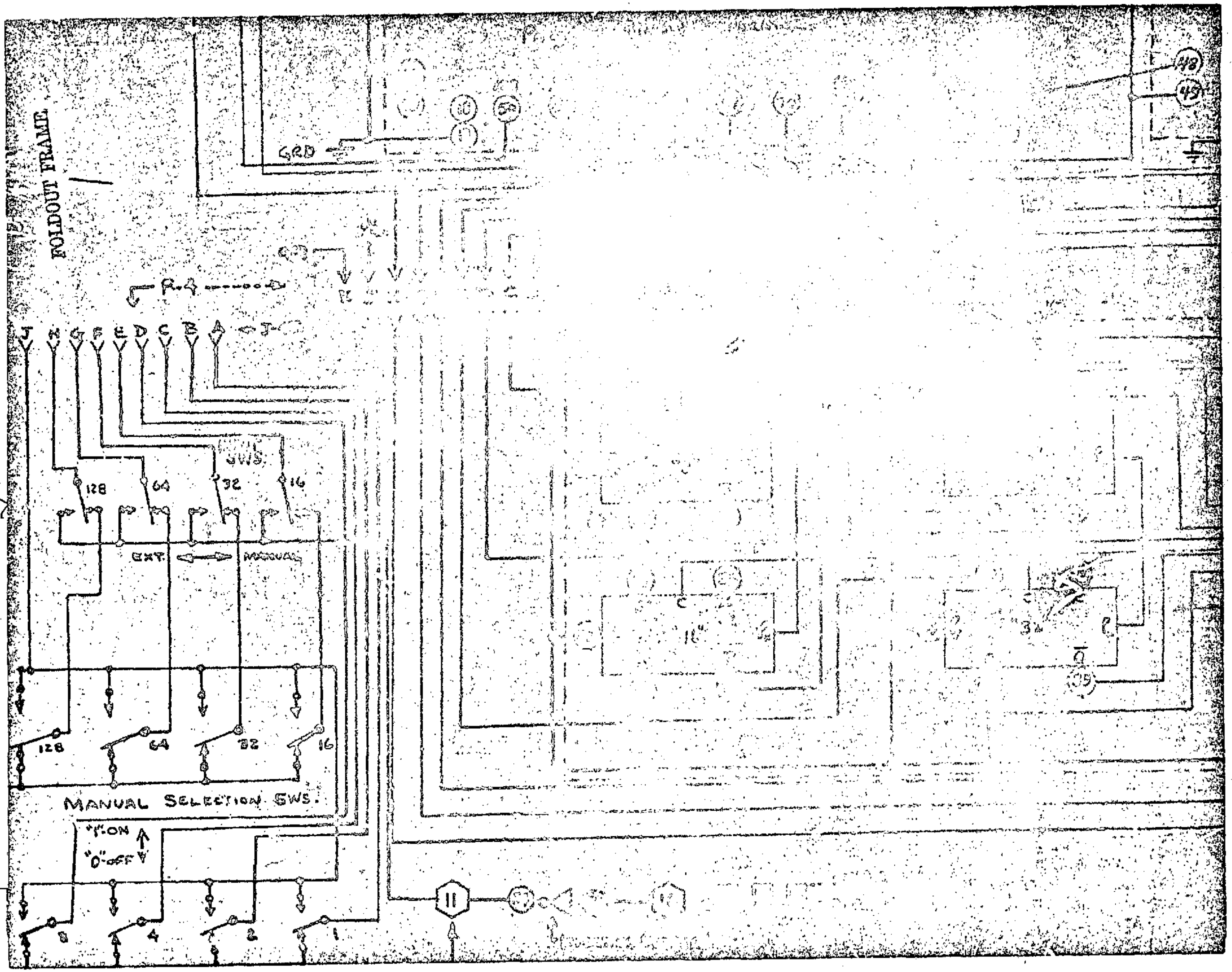
VALVE ASSEMBLY

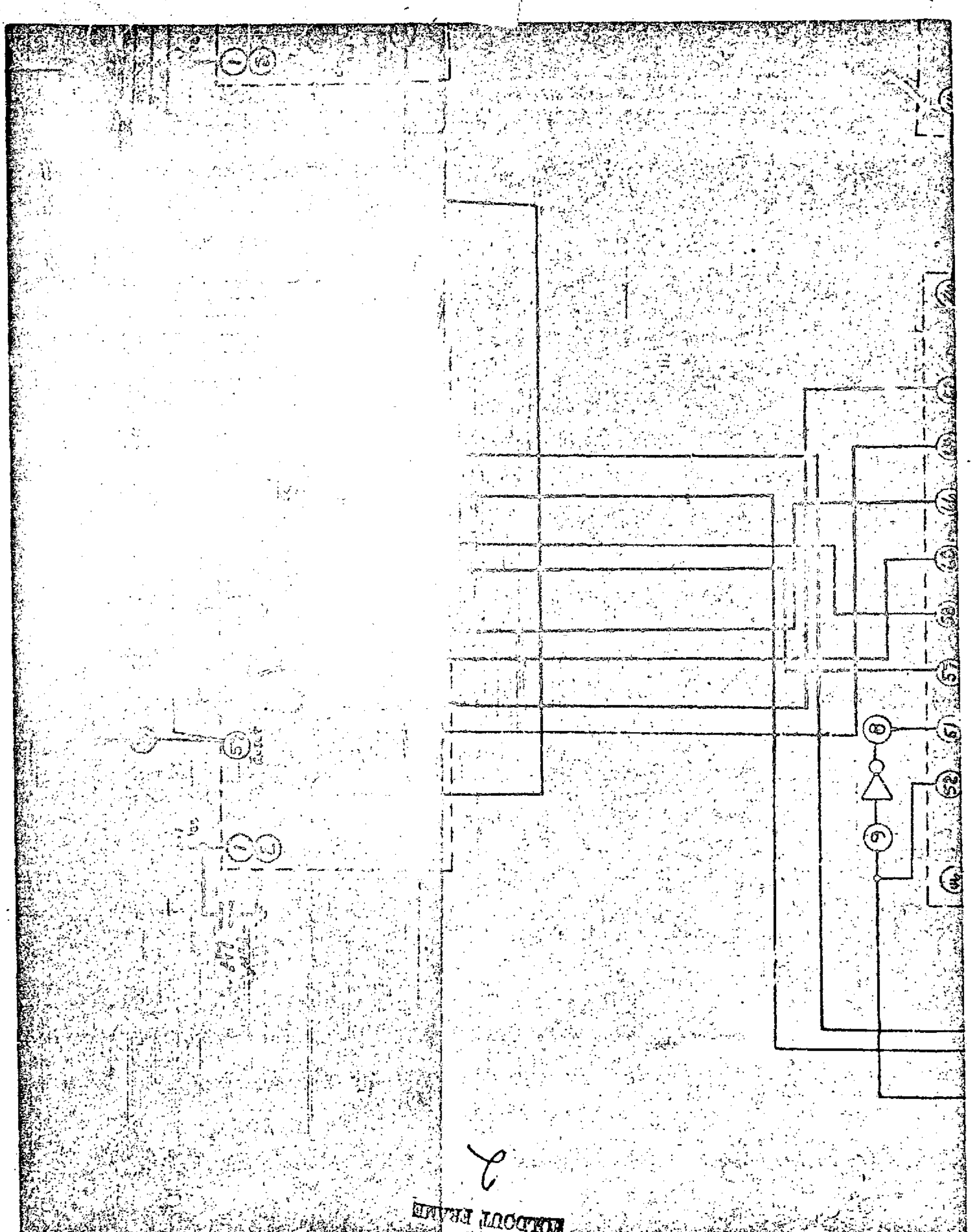
2895

REV.

SCALE FULL

CODE IDENT. NO. 25837


GRD
48
45
J H G F E D C B A
128
64
32
16
SWS.
EXT.
MANUAL
"16"
"32"
128
64
32
16
MANUAL SELECTION SWS.
"1" ON
"0" OFF
8
4
2
1
11

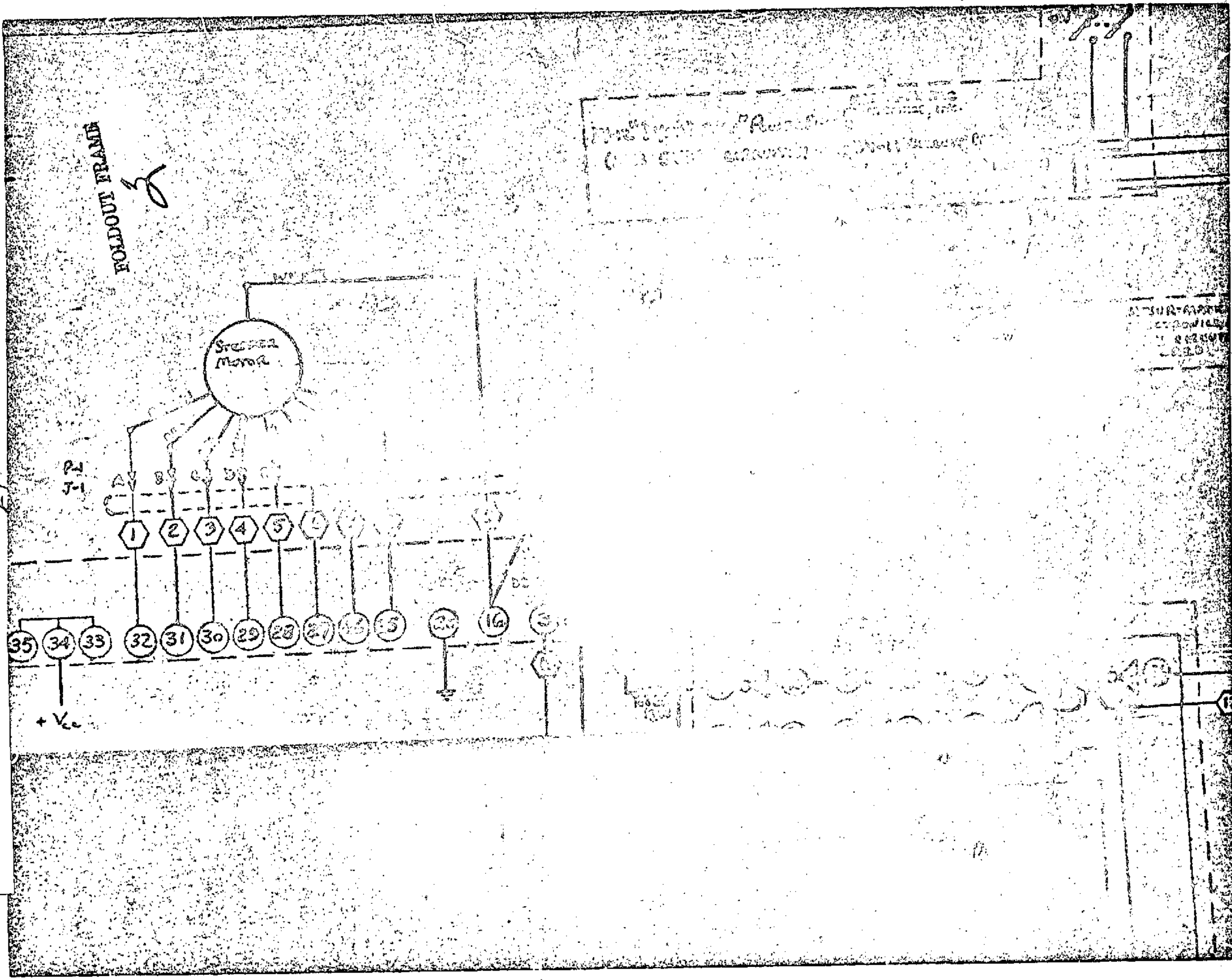


FOLDOUT FRAME

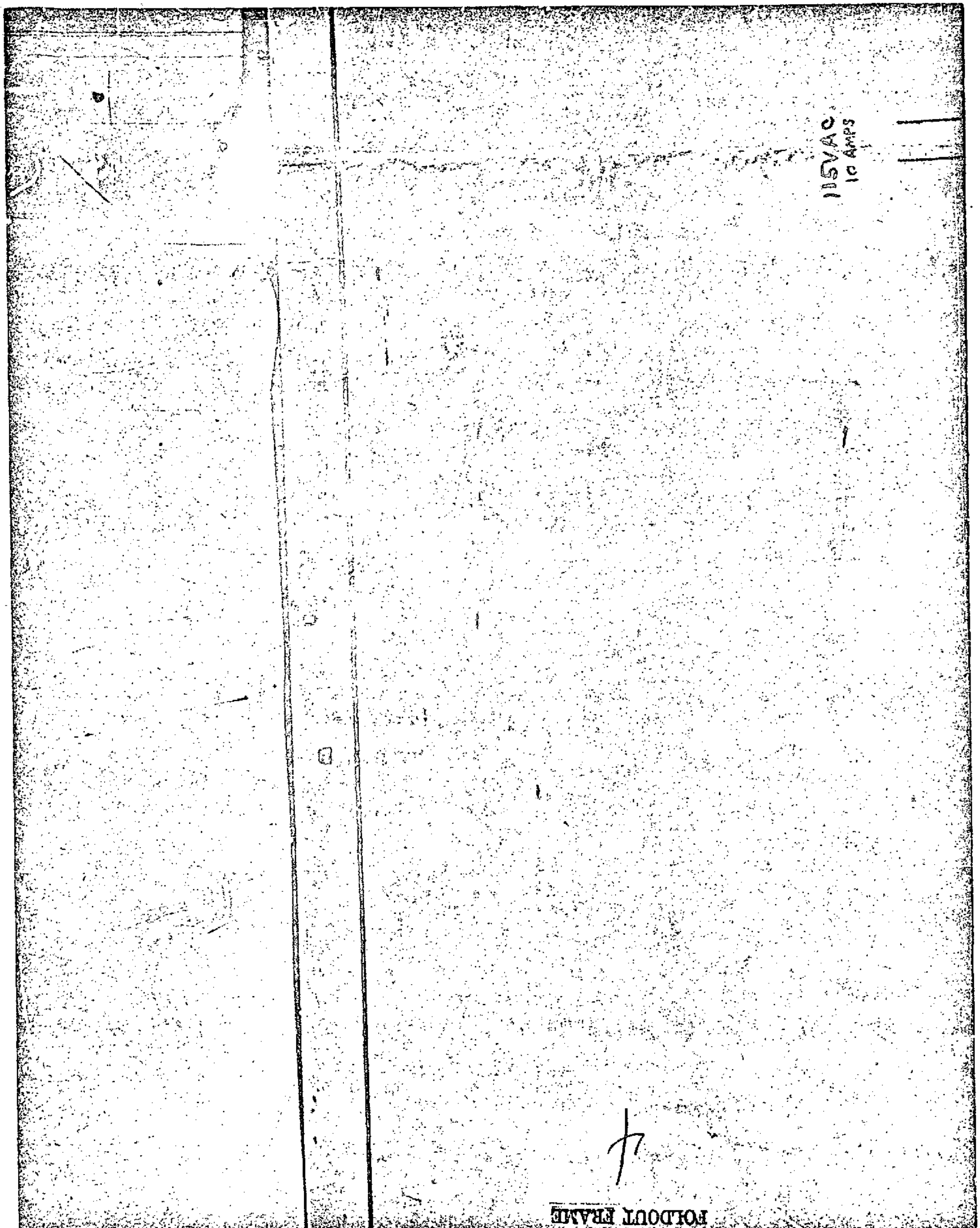
2

FOLDOUT FRAME 2

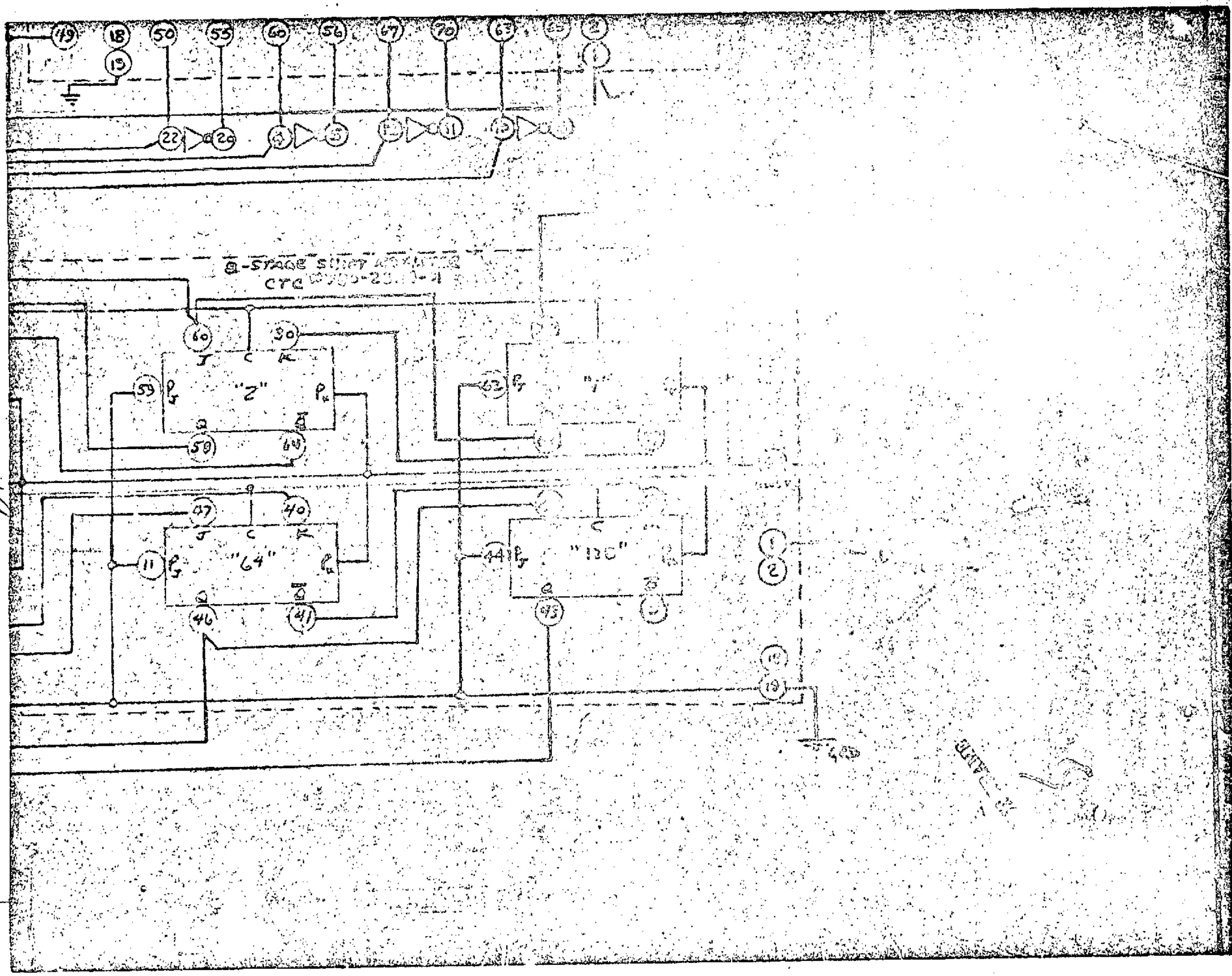
-47-

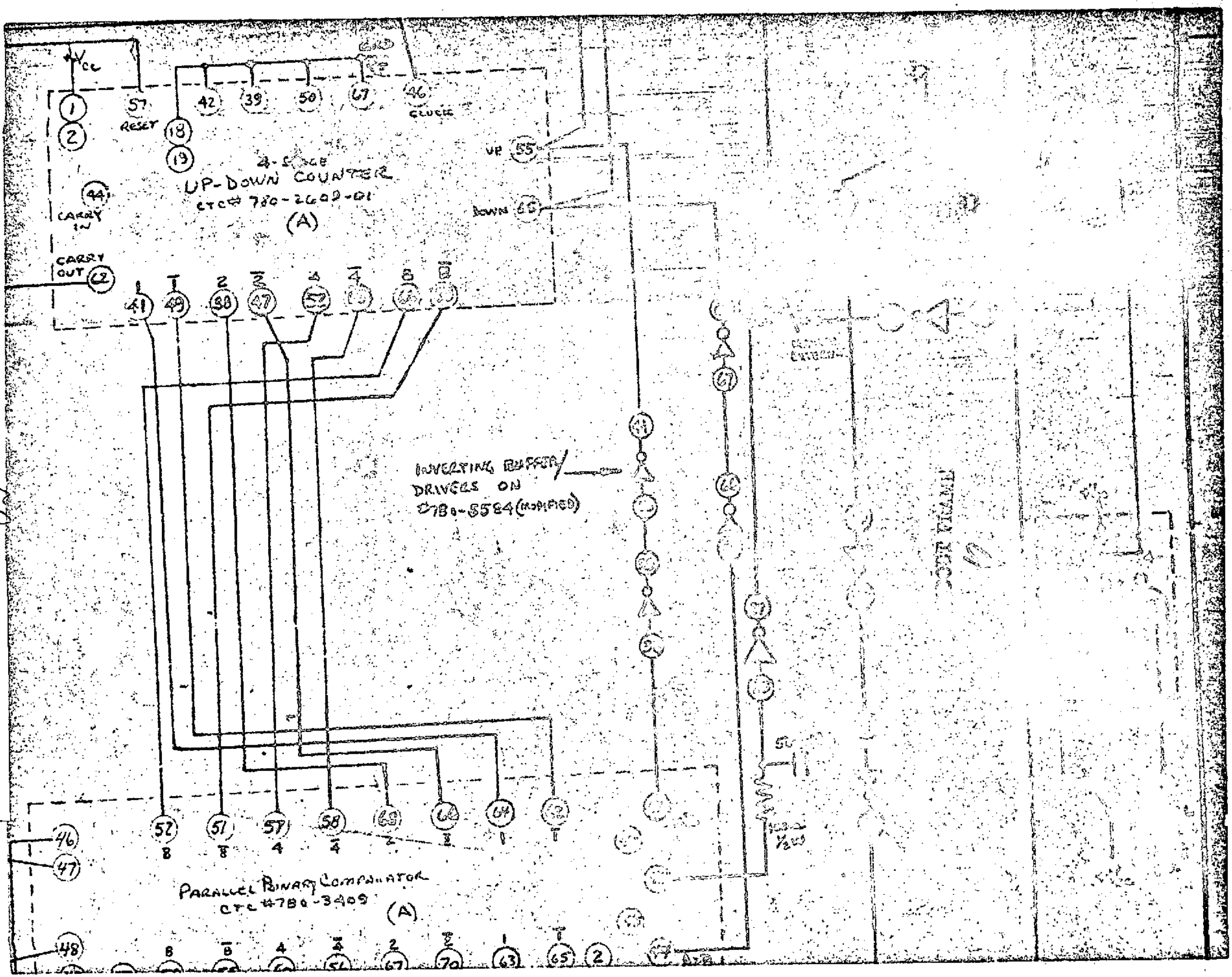


NOT REPRODUCIBLE

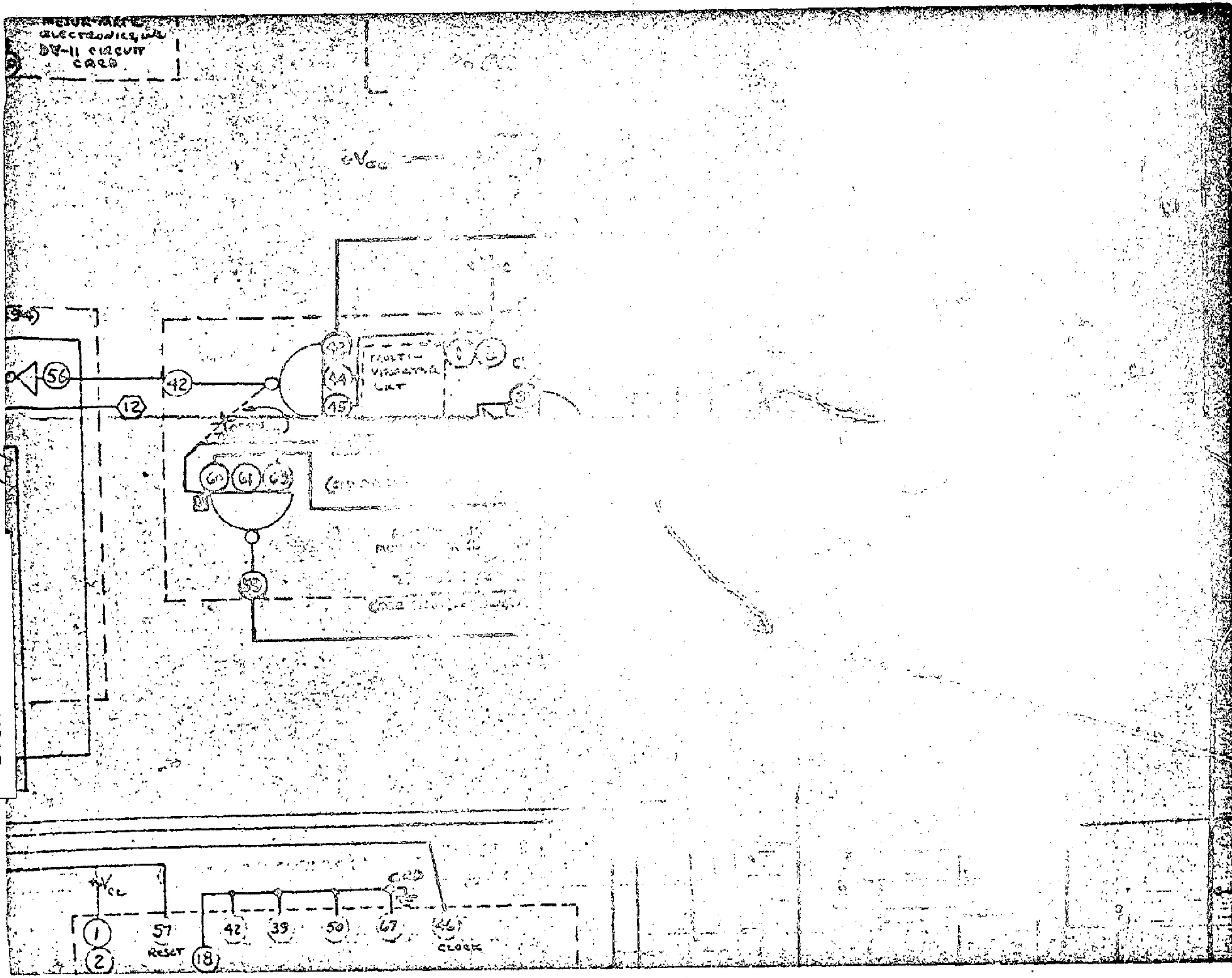


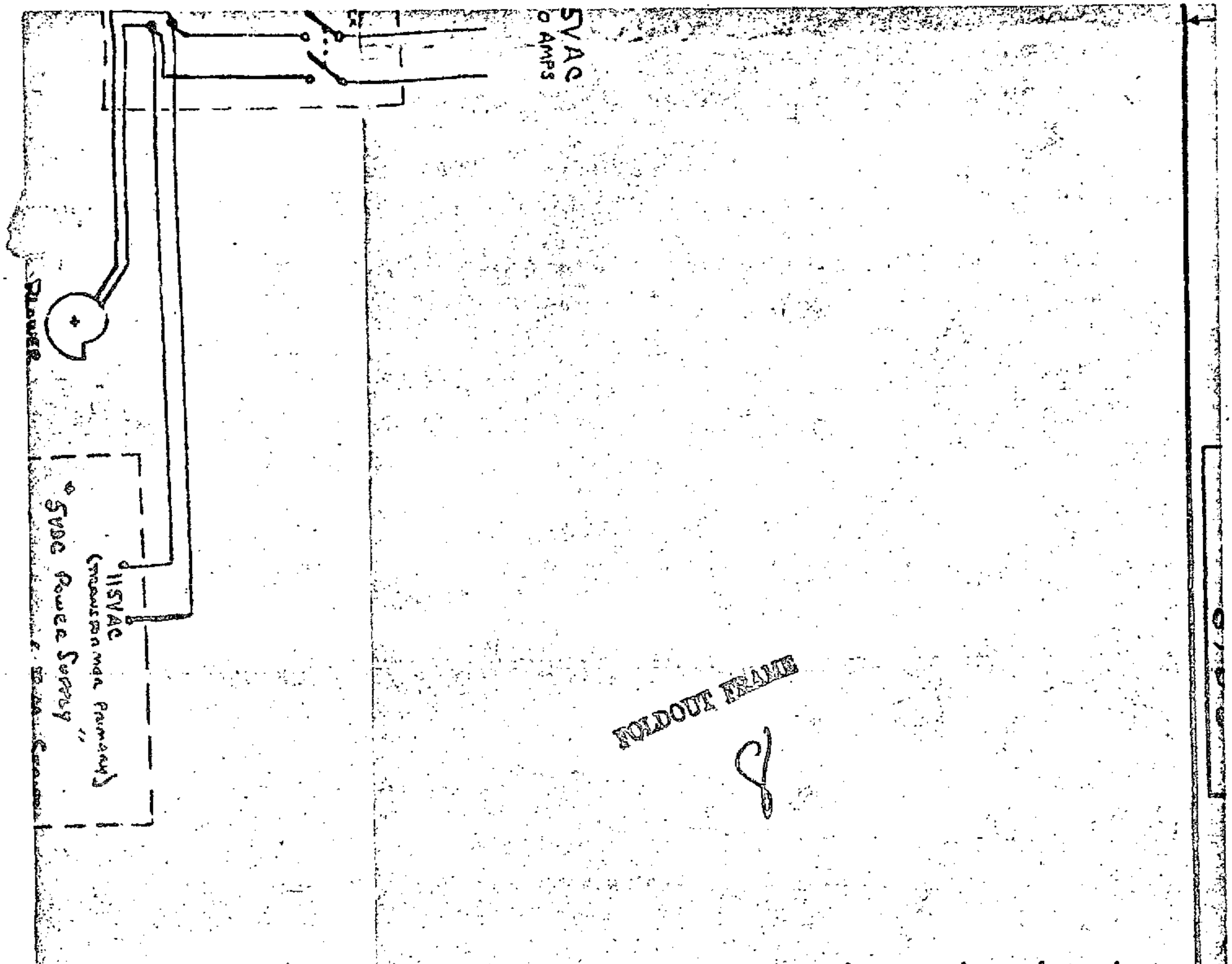
FOLDOUT FRAME


"Z"
"64"
"130"
J C K
P_J P_K
Q $\bar{Q}$


+V_{cc}
RESET
CLOCK
4-STAGE
UP-DOWN COUNTER
CTC# 780-2602-01
(A)
CARRY IN
CARRY OUT
UP
DOWN
INVERTING BUFFER/
DRIVERS ON
#780-5584 (MODIFIED)
PARALLEL BINARY COMPARATOR
CTC #780-3409
(A)

-50-


DV-11 CIRCUIT CARD
56
42
12
MULTI-VIBRATOR CKT
60
61
63
55
57
RESET
1
2
18
39
50
67
46
CLOCK



FOLDOUT FRAME 8

NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	SPECIFICATION	CODE IDENT	UNIT WT	ITEM NO.

LIST OF MATERIALS OR PARTS LIST

DRAWN	L.F.L.	
CHECKED		
APPROVED		
APPROVED		
APPROVED		
APPROVED		
APPROVED		
APPROVED		

APPROVAL DESIGN ACTIVITY

CONTRACT NO.
NAS 8-28166

HLM, INC.

CONTROL CIRCUIT
STEPPER MOTOR WITH
UP-DOWN COUNTER
AND MANUAL CONTROL SIGNAL SIMULATOR

CODE IDENT NO.	SIZE	
25837	D	2918

SCALE | FIRST USE MODEL 1231 | SHEET